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# UCF / KSC COOPERATIVE AGREEMENT

# PROJECT #6

## PRODUCTIVITY TECHNIQUES

### YEAR 1989- 1990 REPORT

March 1991

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# 1. INTRODUCTION

The preliminary study conducted in summer 1989 resulted in the identification of the following productivity techniques which would have a high potential of enhancing the productivity at KSC:

1. The design and prototyping of an ergonomic work stand for overhead operations performed on the orbiter.

2. The use of Voice Data Entry for potential operations at KSC.

3. The study of the use of laser and/ or optical based devices for cavity digitization.

There were a number of other techniques and potential technologies which were identified as potential contributors to the productivity enhancement at KSC. The study for such technologies was deferred to the next phases of the study. Those areas are:

1. The use of Hypermedia in support of operations at KSC.
2. The study of the Data quality at KSC and the devising of "early indicators" based on statistical analysis for potential problems.
3. The effect of cross training vs. specialization on the productivity and quality of work at KSC.

This document reports on the first years effort of the study. The report builds on the analysis conducted in the summer of 1989 and which was documented in a previous report submitted to KSC at the conclusion of that study.

In this executive summary we summarize the outcome of the overall study. Each of the individual study areas is documented separately in the accompanying reports in the Appendices.

## 2. WORK STAND DESIGN AND PROTOTYPING

The summer 1989 study resulted into three conceptual designs for a two-person workstand as well as a set of guidelines for the detailed design. Such designs were formulated after studying a number of operations conducted on the orbiter. The main feature in all of the designs pointed to the need for a back support in any design especially for long duration activities which would require positioning of the operator in a non natural posture - overhead operations. The objectives of this year's study is to develop a detailed design for a complete workstand, build a prototype for the workseat, validate and evaluate the prototype through a laboratory experiment. The final report for this phase is in Appendix I.

### 2.1 The Detailed design:

Two detailed designs were produced. The first one features a hydraulic lift to raise an ergonomic workseat to a working area under the orbiter. The seat can be adjusted to a variety of positions using a controlling joy-stick which controls the back-rest, headrest and the lift. The space around the seat would allow for another worker (helper) to operate. The advantage of this design is that it is flexible enough to accommodate a variety of body sizes and working positions. The main disadvantage of this design is inflexibility with respect to a coverage of larger working area without changing the stand position on the floor. The estimated cost for a prototype based on this design is around $50,000. Subsequent units should be less in price.

The second design features a two seat adjustable workstand without platform. Based on the results of the workseat experiment (see Section 3) using actual tile technicians and typical OPF operations, it was determined that a helper would not be needed if a worker has all the necessary tools, equipment, tool, and material within reach. This eliminated the need for a platform. The design provides for an access to all necessary accessory for an operation as well as protection for any material or chemical dripping on the worker while performing an operation. In a typical operation, the user would sit on the seat and reach for the desired height by the use of the lifting controls to perform an operation. Raising the seat to the proper height is accomplished through either hydraulic or electrical lift.

### 2.2 The Ergonomics Seat:

Based on an initial study a workseat was fabricated with the intention of using it on an existing workstand in an ergonomic experiment. The seat is made up of steel pipes without any controls or adjustment capabilities. The seat fabrication was done through subcontracting with a local steel manufacturing company. The seat was mounted on an existing two-person workstand,obtained from NASA-KSC. The experiment was setup at

the Space Technology Institute (STI) of Brevard Community College (BCC) in Cocoa. STI conducts classes for tile operations as part of training program for tile technicians. The laboratory setup was coordinated with NASA-KSC project officer.

2.3 Experimental Analysis:

An experiment was conducted using the fabricated ergonomics seat and the workstand setup at the Space Technology Laboratory of BCC. The objective of this experiment was to validate the seat dimensions and its effectiveness in improving worker performance and reducing body fatigue. Overhead working environment was created by suspending work surface from the ceiling at the height of about 10 feet from floor which simulates orbiter operations. A number of technicians were recruited from KSC, necessary material, equipment and tools were secured from both IST and KSC. The details of the experiment including design, conduct, findings and results are documented in the accompanying report (Appendix I).

The results of the experimental evaluation revealed that ergonomically designed workseat improves the work performance and provide body comfort during overhead operations especially for long duration activities. More specifically, the following summarize the evaluation results.

1. The seat dimensions were suitable for the conduct of the majority of operations except the lack of head and neck mobility offered by the workseat. However, the original workseat design include the adjustable headrest which was not implemented in the prototype due to cost constraints.

2. The worker's endurance time was significantly increased when the workseat was used. There was an average of 63 percent increase in endurance time.

3. Task accuracy was significantly increased when the workseat was used. This reflects directly on the quality of work.

4. There was no significant difference, with and without workseat in the task completion time. This may be due to relatively short time duration required to complete the experimental tasks. However, when coupled with the large differences in endurance time, there will be a significant difference in task completion times over the course of long work hours.

5. The workseat greatly reduced worker's body discomfort caused by overhead positions. In some specific body parts such as lower legs and thigh, the body discomfort was eliminated.

Based on the above mentioned findings, it is concluded that the ergonomically designed workseat is effective in improving the productivity of tile technicians and in reducing their body fatigue.

The tile technicians' general comments were also compiled during the use of workseat. The following are some comments, which would affect the prototype buildup, shared by most of tile technicians during the use of workseat.

(1) There was not enough clean work area, tools and equipment storage, and waste container. A tool "tray" or some other means for the operator to have access to the tools without changing position is necessary.

(2) The technicians concerned over dripping RTV and other chemicals as well as falling debris. A protection such as a face shield is desirable.

(3) There is a need for information access while work is being done for some operations as well as exchanging information with floor crew.

(4) There is a need for an arm rest in each side.

# 3. VOICE DATA ENTRY (VDE)

The previous effort in the summer 1989 resulted in the development of a training and implementation strategies for the VDE in support of the "step and gap" operation. Such application for the VDE was identified and the software for it was developed by LSOC and Stanford university as part of the SIORA program. Since that time the interest of NASA-KSC and the UCF project team has shifted to different objectives. Specifically, the objectives of this phase, as outlined in working paper appendix II.1, are to study the feasibility of incorporating a microcomputer based VDE with the SPDMS II at KSC and to identify new applications at KSC which may benefit from the VDE technology. While the details of the study are documented in the attached report in Appendix II.2. The following is a summary of the outcome of the study with respect to achieving the two objectives stated above:

## 3.1 The Feasibility of a Microcomputer based VDE system at KSC:

The study in this area was in two fold. The first involved the acquisition of a typical microcomputer based VDE and conducting a typical application experiment at UCF. The second involved a study of the proposed SPDMS II and identifying and resolving any potential compatibility problems. The outcome of the feasibility study indicates that the VDE technology is not reliable enough for the moment to contribute to an increase in the efficiency or the productivity of any of the operations at KSC. However once the technology improves it may have a positive impact on the productivity of a variety of operations at KSC which involve man-computer interaction. This outcome was demonstrated through a laboratory experiment conducted at UCF, the details of which are documented in the accompanying report.

It was also determined that there is no effect on the computer type (Micro vs. otherwise) on the performance of the VDE system. In fact microcomputers are probably better to use for VDE applications since the majority of voice recognition can be done on the micro level before interacting with larger computers for the purpose of data entry or information retrieval.

The shortcomings in the technology cited in the report is in continuous speech recognition, the limitation of the acceptable vocabulary, user dependency, training time, and the remote communication between the user and VDE system which is not always a possible requirement in the KSC environment. Such limitations have to be overcome before such technology would be feasible for use in KSC operations in a manner that will increase productivity and enhance performance.

Studying the proposed SPDMS II and a similar system at UCF reveals no problems of interfacing SPDMS II with any VDE. Most of the commercially available VDE can easily

be interfaced with SPDMS II. In rare cases a software interfacing program may have to be acquired or developed to facilitate the dialogue between the system elements.

3.2 Potential Application at KSC:

A model was developed to aid in the identification and evaluation of potential jobs which may be amiable to the use of VDE technology. The model considers the technological demands for a successful job performance, as well as the benefits which may materialize if VDE is used. Factors such as the working conditions, need for free hand environment, job duration, the vocabulary used in performing the operations, training requirement and the impact on the productivity are incorporated in the model. Jobs are evaluated against the various factors based of a point scale and the viability of the VDE application is assessed. The model has been used in identifying "Problem Reporting" as one such operation which may benefit from the VDE technology. A parallel effort is being conducted in identifying other jobs and in collecting the necessary vocabulary for the Problem Reporting prototyping.

## 4. CAVITY DIGITIZATION

The summer 1990 effort resulted in demonstrating the technical feasibility of obtaining a 3-D mapping of a cavity through the use of optical/ laser based technology. The study also identified equipment manufacturers and potential problems of implementation in the KSC environment. A grant from FHTIC to UCF provides partial support for this component of the study and calls for UCF to team up with an industry for system development.

The objective of the next phase of the study is to build and demonstrate a device which through the use of laser and/or optical technology would collect 3-D descriptive information of a tile cavity in the orbiter and display it in a form that would enable the fabrication of a replacement tile. However the effort is continuing, the following is a point summary of what have been accomplished so far. The details of the effort is the accompanying report (Appendix III):

1. A joint project between LSOC and UCF was initiated. The project team is composed of 4 UCF researchers and 2 LSOC researchers. The basis for the project was an interim report submitted to NASA-KSC and LSOC. Appendix III.1 is a copy of the interim report.

2. A complete plan for the project, its activities and durations, estimated cost and the responsibilities of each partner was detailed and approved by the project leaders. Appendix III.2 is the details of the plan.

3. UCF pledged a partial fund of $50,000 for the project through a grant from Florida High Technology and Industry Council (FHTIC) and LSOC pledged $125,000 for the project from its own R&D funds.
   Appendix III.3 is LSOC commitment.

4. Two types of technologies have been identified as feasible technologies (a) Laser scan based system and (b) Image processing based system.

5. For each of the two systems above, technology developers were identified as the National Research Council of Canada (NRCC) and its licensees for the laser based technology and Lockheed Missile and Space Co. (LMSC) for the image processing based technology.

6. Technical teams have visited the two companies where the technology are being developed. On each visit the technology was demonstrated to the team.

7. Currently the project team is in the process of evaluating the technology and soliciting proposals from the respective companies.

8. In a parallel effort UCF has acquired a laser probe and a controlling mechanism for the purpose of experimenting on the use of the lasers in obtaining 3-D images and for possible use in the quantification of orbiter oscillation. Work is in progress in this area. Appendix III.3 is a tally of the experiments in this area.

## 5. TECHNOLOGY TRANSFER

A total of 12 technical papers and conference participation was conducted by the research team over the span of the last year. Following is a tally of the paper's titles and conferences. Sample publications are in Appendix IV.

1. Cindy L. Mollakarimi, Tamim S. Hamid, (Lockheed), UCF project recognized, "Remote Voice Training: A Case Study on Space Shuttle Applications," AVOIS '89 Conference Proceedings and presentation, September 12-14, 1989, Los Angeles, CA.

2. Yasser A. Hosni, John Scarboro, (UCF), Tamim Hamid (Lockheed); 12th Conference on Computers and Industrial Engineering, March 12-14, 1990, Orlando, Florida.

3. Tim Barth, Yasser Hosni, and William Swart, "Improving Productivity of Space Shuttle Processing," Proceeding IIE Aerospace and Defense Division 13th Annual Spring Conference, Orlando, FL, February 14, 15, 16, 1990.

4. Yasser A. Hosni, Chin H. Lee, (UCF), Timothy S. Barth, and Cedric Hill, (NASA-KSC), "Ergonomically Designed Workstand for Overhead Operations: Case of Heat-Tile Replacement in the Space Shuttle," Human Aspects of Advanced Manufacturing and Hybrid Automation, 2nd International Conference, Honolulu, Hawaii, August 12-16, 1990.

5. Yasser Hosni (UCF), Tamim Hamid (Lockheed); "Speech Recognition and Synthesis, Training and Implementation Strategies"; Human Aspects of advanced Manufacturing and Hybrid Automation, 2nd International conference; Honolulu, Hawaii, August 12-16, 1990.

6. Yasser A. Hosni, John Creech (UCF), Timothy S. Barth, and Cedric Hill, (NASA-KSC); "Workstand Design for Overhead Operations; Case of Heat-Tile Replacement in Space Shuttle"; 1990 International Industrial Engineering Conference; San Francisco, CA, May 20-23, 1990.

7. Presentation: "Ergonomic Workstation for Overhead Operations" Innovation 91. The 4th Annual Conference of Universities, Industry, Entrepreneurs & Government for Joint Technology Commercialization. Evaluate for innovation 90, however will be considered for Innovation 91 upon completion of prototype.

8. Yasser A. Hosni, Daniel Nasser, Jueng-Shing Hwang, and Labiche Ferreira; "Non-Contact, 3-D, Object Digitizing Systems for Die-Manufacturing"; Paper submitted for the 1990 Society for Integrated Manufacturing Conference, San Antonio, Texas, October 28-31, 1990.

9. Yasser Hosni, Jueng Shing Hwang and Labiche Ferreira, "Tool Path Generation From Surface Mapping of an Object", PROCIEM '90, Tampa, Florida, November 14-16 1990.

10. Yasser Hosni, Daniel Nasser, Jueng-Shing Hwang and Labiche Ferreira, "Non-Contact, 3-D, Object Digitizing Systems for Die Manufacturing", Computers and Industrial Engineering Conference, Orlando, Florida, March 11-13 1991.

11. Yasser Hosni, Tamim S. Hamid and Andrew E. Okraski, "Hypermedia Based System for Space Shuttle Processing", Computers and Industrial Engineering Conference, Orlando, Florida, March 11-13 1991.

12. Chin H. Lee, Yasser Hosni, Lisa Guthrie (UCF), Timothy Barth, and Cedric Hill (NASA-KSC), "Design and Evaluation of a work seat for Overhead Operations", International Industrial Ergonomics and Safety Conference '91, Lake Tahoe, NV June 10-14, 1991.

## 6. PROJECT TEAM

Over the span of the last year a total of four faculty members and 8 graduate students have participated in the project activities. Following is a tally of the project team, responsibilities, and status of each:

1. Dr. Yasser Hosni, Professor, P.I. and Project Director

2. Dr. William Swart, Professor, Co-P.I.

3. Dr. Chin Lee, Asst. Professor, Workstand Component

4. Dr. Robert Safford, Visiting Associate Professor, Voice Data Entry and Cavity Digitization.

5. Mr. Jueng Shing Hwang, Cavity Digitization, M.S.I.E. (Computer Integrated Manufacturing), Expected graduation date - Spring 1991.

6. Mr. Labiche Ferreira, Cavity Digitization, M.S.I.E. (Computer Integrated Manufacturing), Expected graduation date - Spring 1991.

7. Mr. Thomas Pax, Cavity Digitization, M.S.Computer Engineering, Expected graduation date - Fall 1991.

8. Mr. Yuanlin Shi - Cavity Digitization, M.S.Computer Engineering, Expected graduation date - Fall 1992.

9. Mr. Kenneth Cole - Voice Data Entry, M.S.I.E. (Engineering Administration), Expected graduation date - Fall 1991.

10. Miss Lisa Guthrie - Workstand Design, M.S.I.E. Expected graduation date - Fall 1991.

11. Mr. Andrew Okraski - Hypermedia Applications, Ph.D. Industrial Engineering.

12. Mr. Tamim Hamid - Hypermedia Applications, M.S.I.E. (Computer Integrated Manufacturing), Expected graduation date - Spring 1991.

    In addition, 3 students graduated in the phase of the project: 1989-1990.

    Two researchers form LSOC have joined the team in support of the Cavity Digitization component.

# 7. APPENDICES

Appendix I. Workstand Design Component

- Appendix I.1 Working paper for the workstand design
- Appendix I.2 Workseat Experiment Report

Appendix II. Voice Data Entry

- Appendix II.1 Working paper for the VDE component
- Appendix II.2 Voice Data Entry Technical Report

Appendix III. Cavity Digitization Report

- Appendix III.1 Cavity Digitization Interim Report
- Appendix III.2 UCF/LOSC Project Plan
- Appendix III.3 Tally of experiments for laser equipment at UCF.

Appendix IV. Sample Publications

## Appendix I. Workstand Design Component

Appendix I.1 Working paper for the workstand design

Appendix I.2 Workseat Experiment Report

# Appendix I.1 Working paper for the workstand design

UNIVERSITY OF CENTRAL FLORIDA
INDUSTRIAL ENGINEERING PROJECT
UCF/KSC COOPERATIVE AGREEMENT

WORKING PAPER FOR PHASE II - FALL 1990 - SPRING 1991

## WORKSTAND DESIGN COMPONENT

**OBJECTIVE:**

This working paper is to report the objective, procedure, and outcome for the phase III of the study. The objectives of the study phase are:

- To design an ergonomic workstand for overhead operations performed on the orbiter.

- To produce a prototype of the workseat which is a main component of the workstand.

- To validate the workseat design and evaluate its effectiveness through a laboratory experiment.

**PROCEDURE:**

- Set up experimental evaluation at Brevard Community College in Cocoa.

- Recruit tile technicians.

- Conduct experimental evaluation of the prototype of workseat using tile technicians as subjects.

- Analyze the experimental data.

- Document experimental evaluation and data analysis in a technical report.

**OUTCOME:**

1) Workseat evaluation data.

2) Technical paper documenting the findings of this phase.

3) Improved design.

**UCF TEAM INVOLVED:** Dr. Yasser Hosni, Dr. Chin Lee, Lisa Guthrie

# Appendix I.2 Workseat Experiment Report

UNIVERSITY OF CENTRAL FLORIDA/KSC
COOPERATIVE AGREEMENT

PROJECT #6

PRODUCTIVITY TECHNIQUES

# Workstand Design Component

## Phase II Report

Spring 1991

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WORKSTAND DESIGN, PROTOTYPING, AND EVALUATION

The summer 1989 study resulted into three conceptual designs for a two-person workstand as well as a set of guidelines for the detailed design. Such designs were formulated after studying a number of operations conducted on the orbiter. The main feature in all of the designs pointed to the need for a back support in any design especially for long duration activities which would require positioning of the operator in a non natural posture - overhead operations. The objectives of this year's study is to develop a detailed design for a complete workstand, build a prototype for the workseat, validate and evaluate the prototype through a laboratory experiment.

## 1.0 Detailed Design

Two detailed designs were produced. The first one is that shown in Figure 1 (A and B). The main features include a hydraulic lift to raise an ergonomic workseat to a working area under the orbiter. The seat can be adjusted to a variety of positions using a controlling joy-stick which controls the back-rest, headrest and the lift. The space around the seat would allow for another worker (helper) to operate. This design is the result of several levels of improvement above the initial design developed in previous phases. A hydraulic lift to raise the ergonomic workseat to the 8' to 12.5' high work areas under the orbiters is a major design feature. This design takes the individual into account in the initial stages of design by considering anthropometric, biomechanical, physiological, and anatomical properties of the individual to reduce fatigue, improve efficiency, and thus enhance performance.The adjustable workseat can assume a variety of supported positions with a joy-stick which controls the back-rest, headrest, and the lift. The segment of the chair supporting the lower leg is also manually adjustable to accommodate a larger population size range.

The advantage of this design is that it is flexible enough to accommodate a variety of body sizes and working positions. The main disadvantage of this design is inflexibility with respect to a coverage of larger working area without changing the stand position on the floor and high cost. The estimated cost for a prototype based on this design is between $50,000 and $75,000 depending on the type of material used. Subsequent units should be less in price.

The second design is shown in Figure 2. This design features a two seat adjustable workstand without platform. Based on the results of the workseat experiment using actual tile technicians and typical OPF operations, it was determined that a helper would not be needed if a worker has all the necessary tools, equipment, tool, and material within reach. This eliminated the need for a platform. Ergonomically designed workseats will be mounted on a commercially available scissor lift. This design will include all necessary accessories for an operation as well as protection for any material or chemical dripping on the worker while

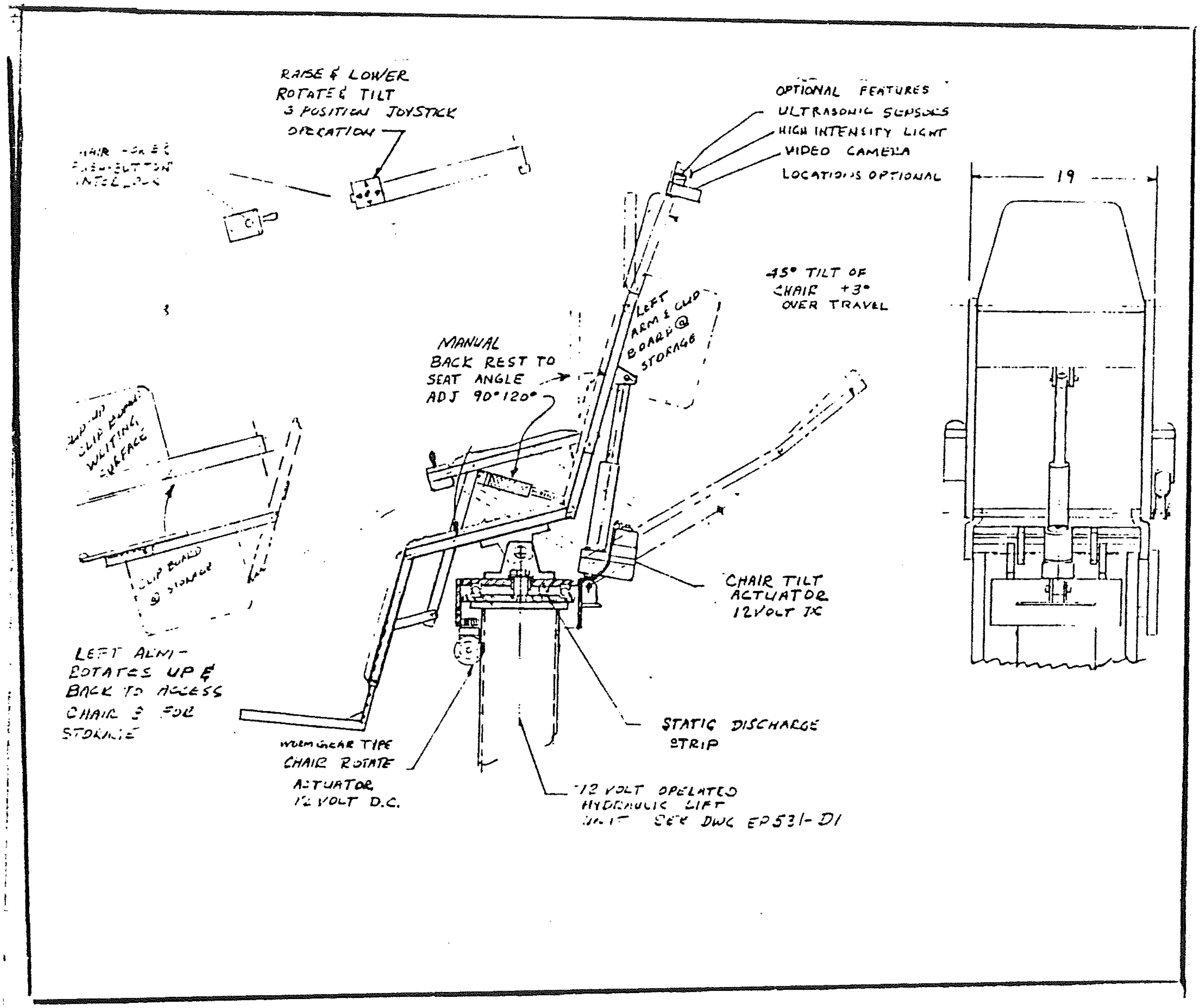



Figure 1A. Workseat; Detailed Design 1

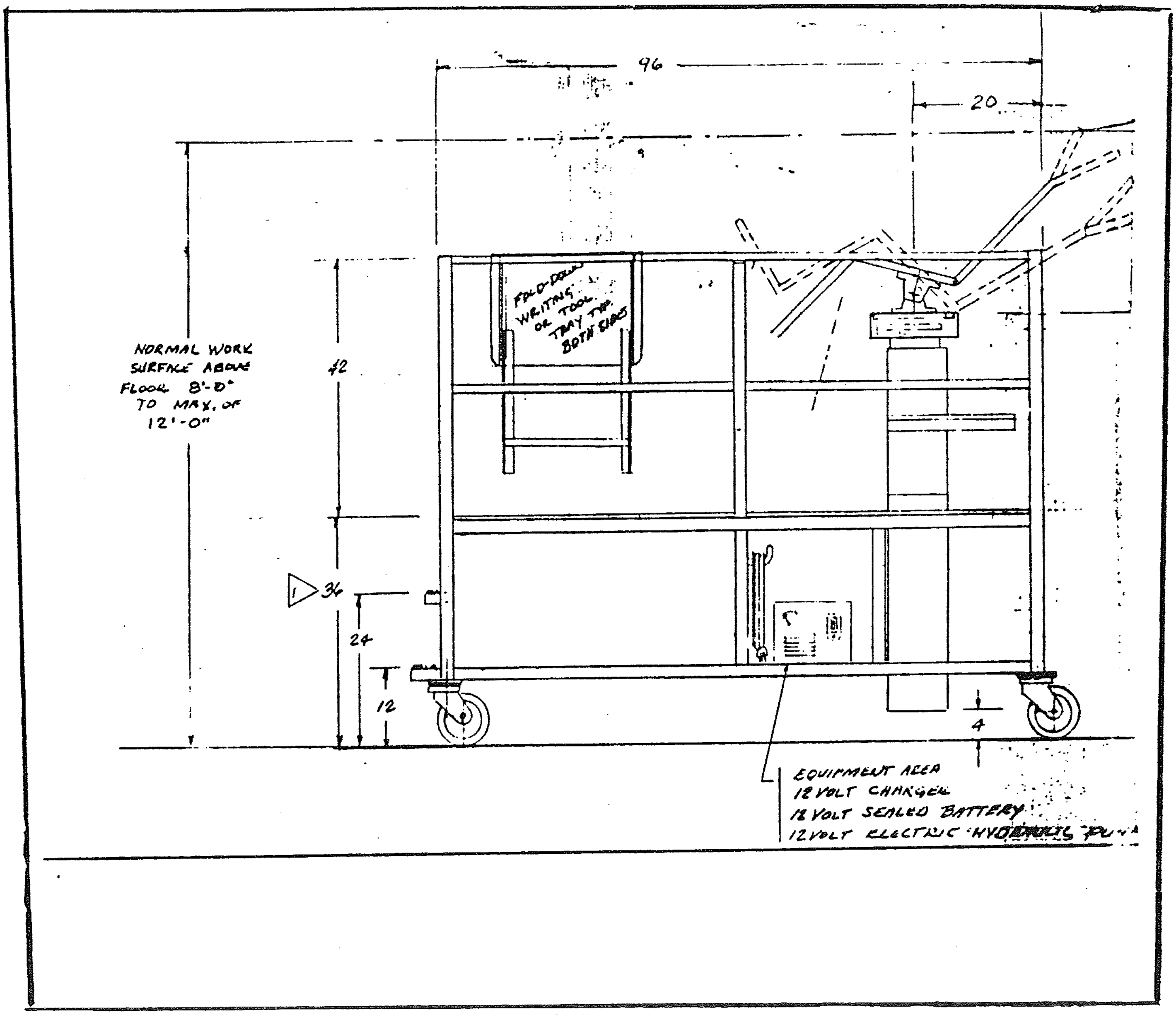



Figure 1B. Workstand; Detailed Design 1

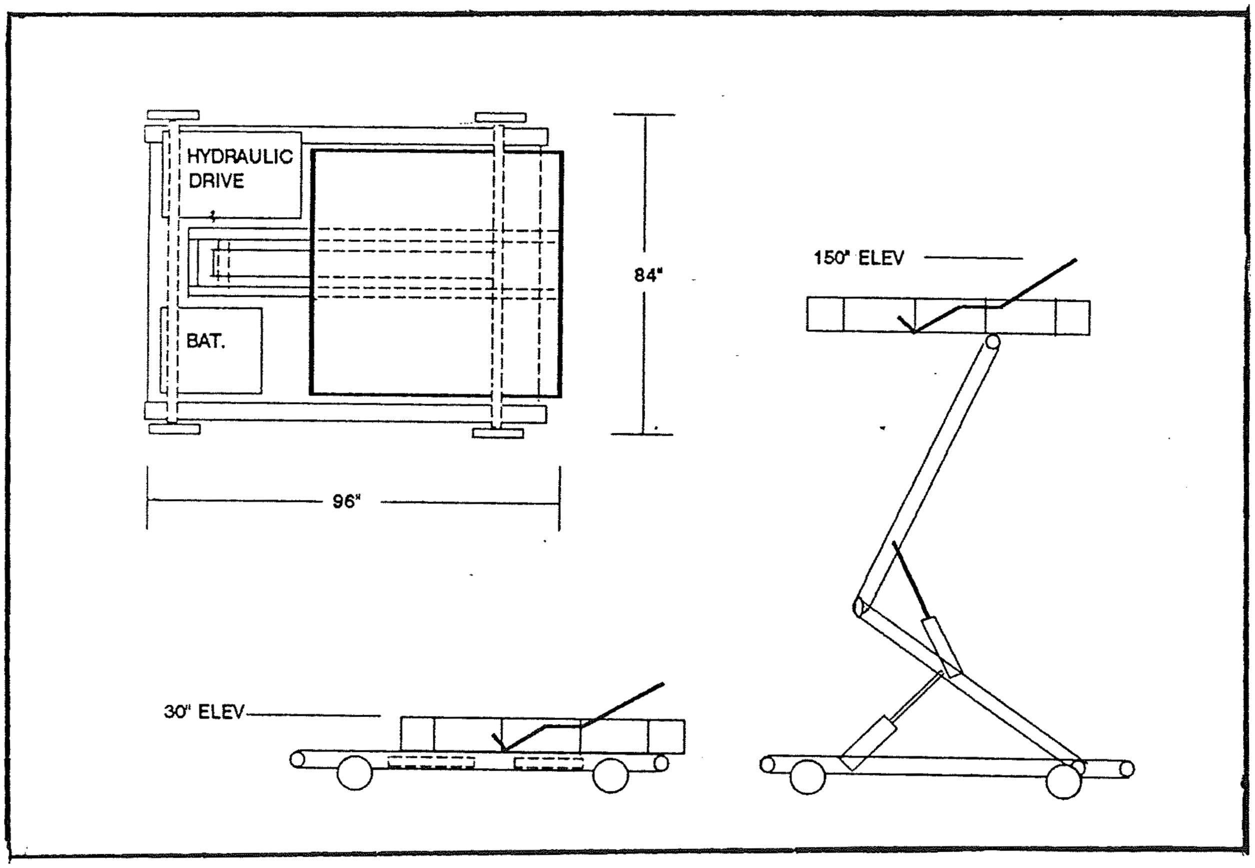



Figure 2. Workstand, Detailed Design 2

performing an operation. In a typical operation, the user would sit on the seat and reach for the desired height by the use of the lifting controls to perform an operation. Raising the seat to the proper height is accomplished through either hydraulic or electrical lift. The cost for a unit is expected to be approximately $25,000.

## 2.0 The Prototyping of the Ergonomic Workseat:

Based on an initial study a workseat was fabricated with the intention of using it on an existing workstand during the experimental evaluation. The seat is made up of steel pipes without any controls or adjustment capabilities. Figure 3 shows the seat design and its dimensions. The seat fabrication was done through subcontracting with a local steel manufacturing company. The seat was mounted on an existing two-person workstand, obtained from NASA-KSC, as shown in Figure 4, and evaluated through an experiment conducted at the Space Technology Institute (STI) of Brevard Community College (BCC) in Cocoa.

## 3.0 Experimental Evaluation:

An experiment was conducted using the fabricated ergonomic workseat and the workstand setup at the STI of BCC. STI conducts classes for tile operations as part of training program for tile technicians. The laboratory setup was coordinated with NASA-KSC project officer. The objective of this experiment was to validate the seat dimensions and its effectiveness in improving worker performance and reducing body fatigue. Overhead working environment was created by suspending work surface from the ceiling at the height of about 10 feet from floor which simulates orbiter operations. A number of technicians were recruited from KSC, necessary material, equipment and tools were secured from both STI and KSC.

### 3.1 Evaluation Techniques

The experimental evaluation consisted of both objective and subjective evaluation; human performance measurement and subjective evaluation. The human performance measurement serves as a method for quantitatively measuring the effects of the implementation of the proposed workseat by providing an accurate way to measure changes in performance parameters. The subjective evaluation reveals very useful qualitative information associated with discomfort and muscle fatigue by measuring the levels of discomfort associated with each posture during the performance of the experimental tasks.

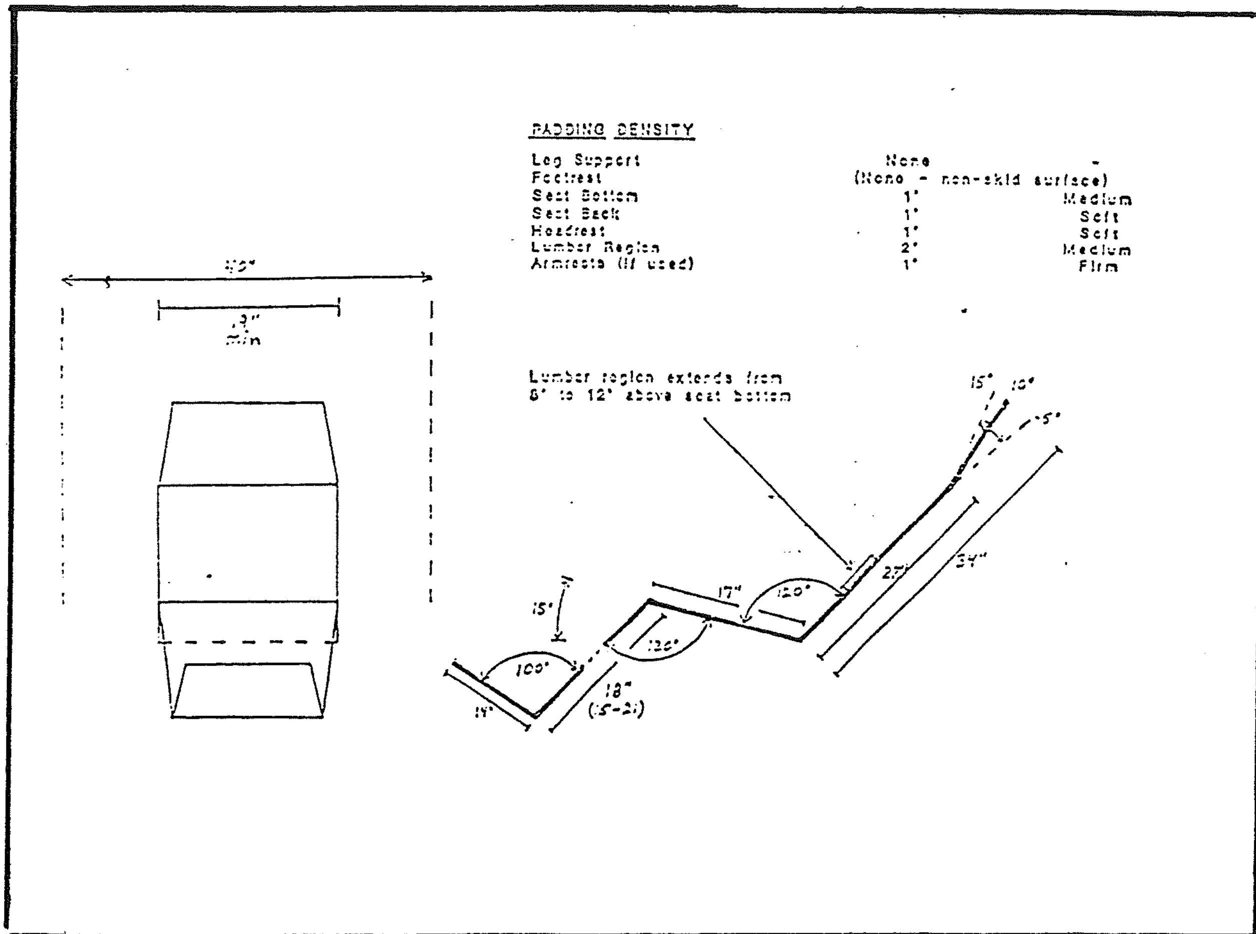



Figure 3. Ergonomic Workseat; Design and Dimensions

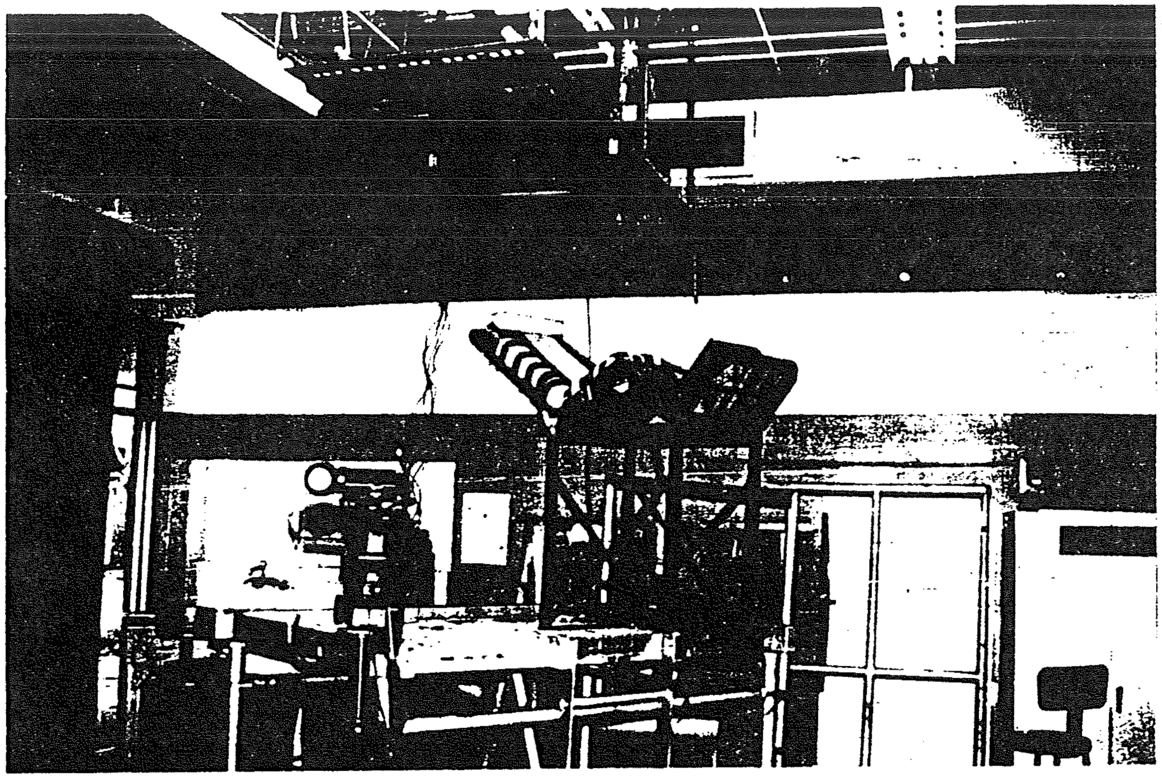


Figure 4. Ergonomic Workseat on Workstand

### 3.2 Experimental Setup

With the cooperation of the IST at Brevard Community College and the tile technicians recruited from KSC, the experimental evaluation was conducted by simulating the actual Thermal Protection Repair and Maintenance Procedures as well as two additional general application tasks. Thus, the evaluation results will be a direct reflection of the possible improvement of workers at KSC and others performing similar overhead operations elsewhere.

Process P-601 **Installation of Pillow (Alumina) Gap Fillers** and P-301 **Tile Installation** were simulated because of the high frequency of their occurrence at the OPF and ease of simulation. The simulated orbiter surface for Processes P-601 and P-301 is shown in Figure 5. Figures 6 and 7 show a subject performing the processes. In addition, **Rotary Pursuit Tracking** and **Weighted Overhead Work** were also included to simulate general overhead task applications.

Rotary Pursuit Tracking is designed to allow for human performance measurements in the area of accuracy by simulating fine motor skills and is a commonly accepted and recognized method of measurement in the ergonomics field. Simply, the task involves a fluorescent light source rotating in a circular motion and a stylus wand with a photocell at the tip as shown in Figure 8. The subjects pursued the moving light target with the stylus, attempting to keep the stylus and light moving together on the circular path. Figure 9 shows a subject performing the tracking task in the standing position. The photocell initiates the digital stop clock shown in Figure 10. The clock measures the cumulative time of successful pursuit. By keeping the time of the task, sensitivity of the sensor, and speed of rotation constant for all subjects, an effective measurement of accuracy was easily obtained.

The Weighted Overhead Task was serves a simulation of overhead work involved heavy objects. The subject was to align a weighted box in the cavity positioned overhead. The subject further holds the weighted box overhead in that position as long as they possibly can without moving the box from the cavity. Figure 11 shows a subject holding the weighted overhead box during the weighted overhead task.

### 3.3 Performance Parameters

The performance parameters served as the base of the experimental evaluation. During the actual process simulations, the tile technicians' efforts were timed, observed, and video taped for further study. The parameters measured were task completion time during processes P-601 and P-301, endurance time during Weighted Overhead Task, task accuracy during Rotary Pursuit Tracking, and body discomfort throughout the experiment.

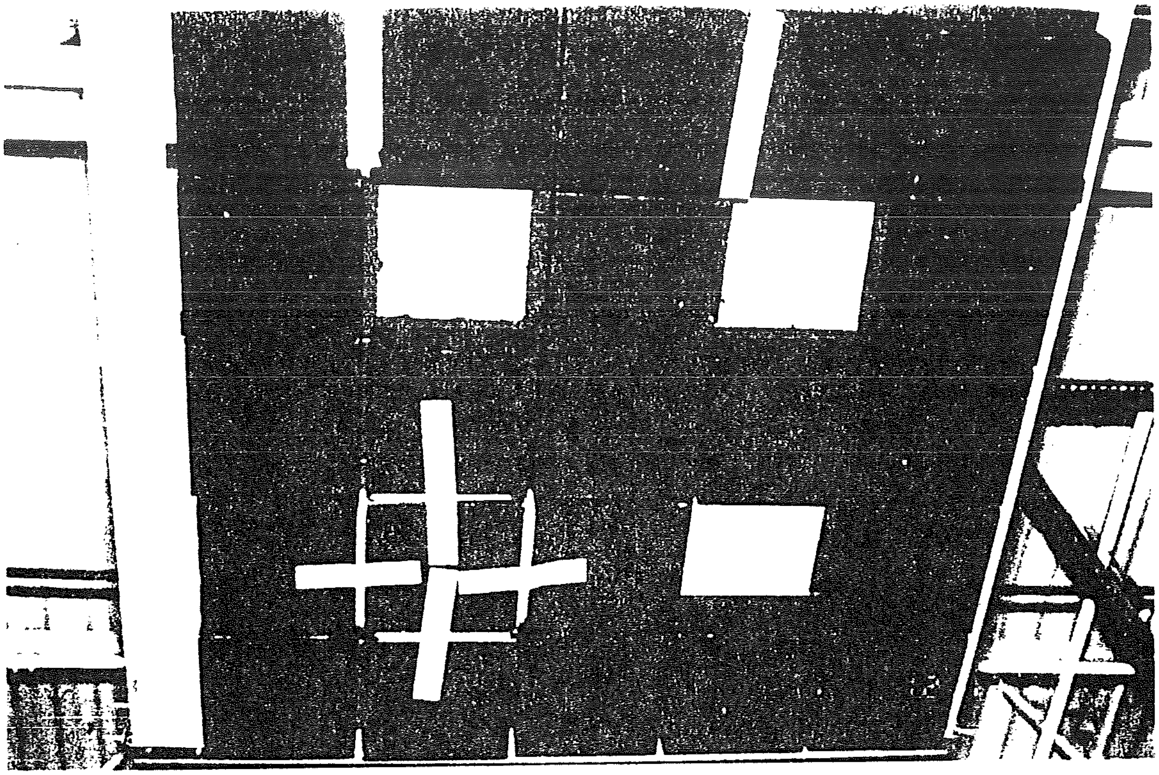


Figure 5. Simulated Orbiter Surface

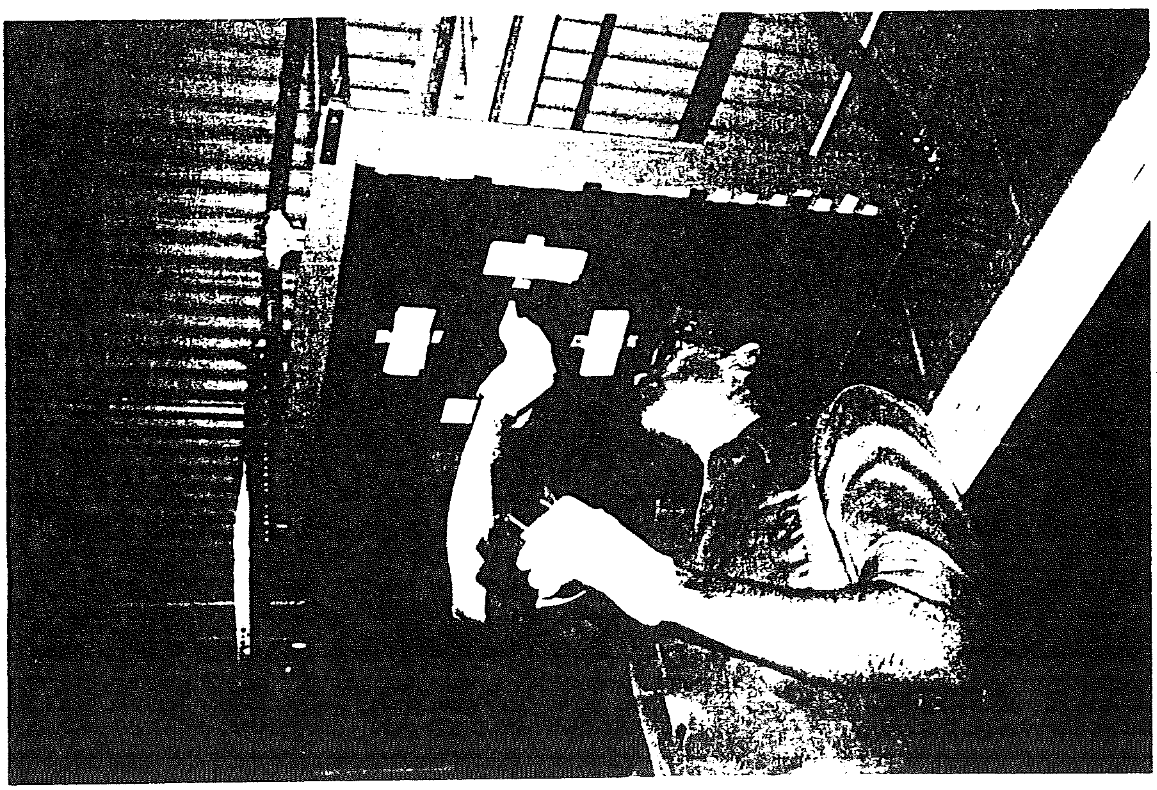


Figure 6. Subject Performing P-601

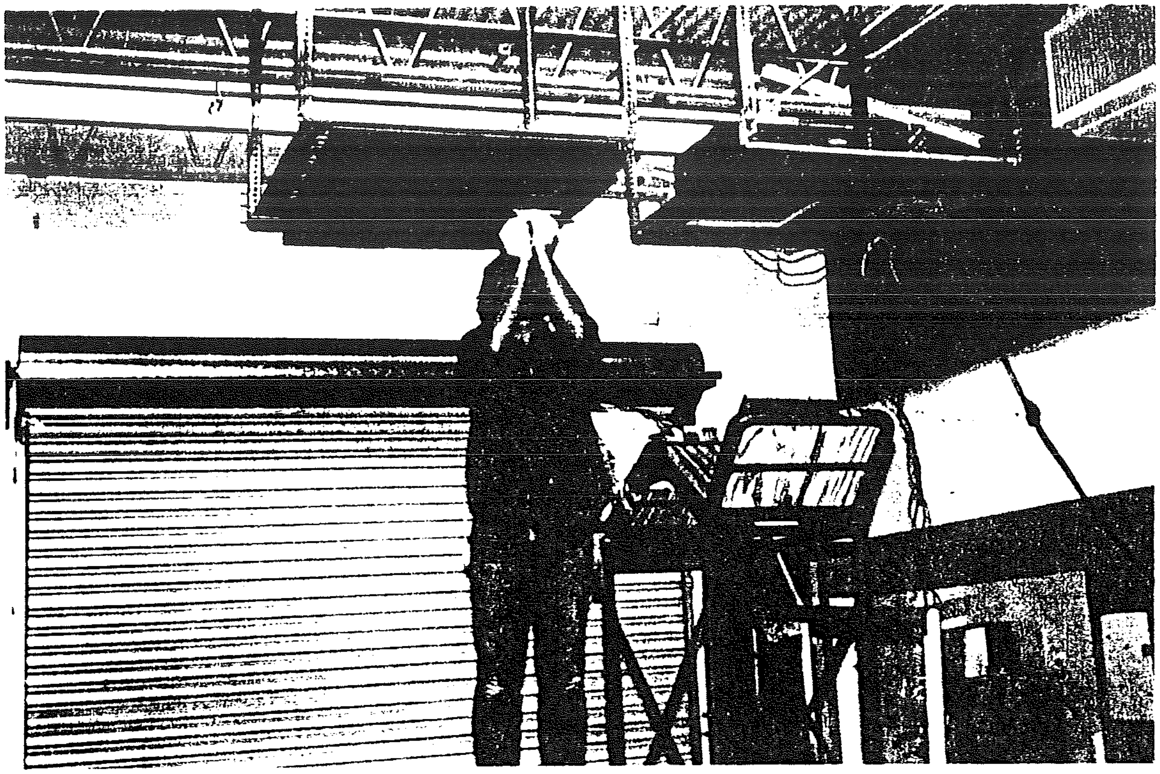


Figure 7. Subject Performing P-301

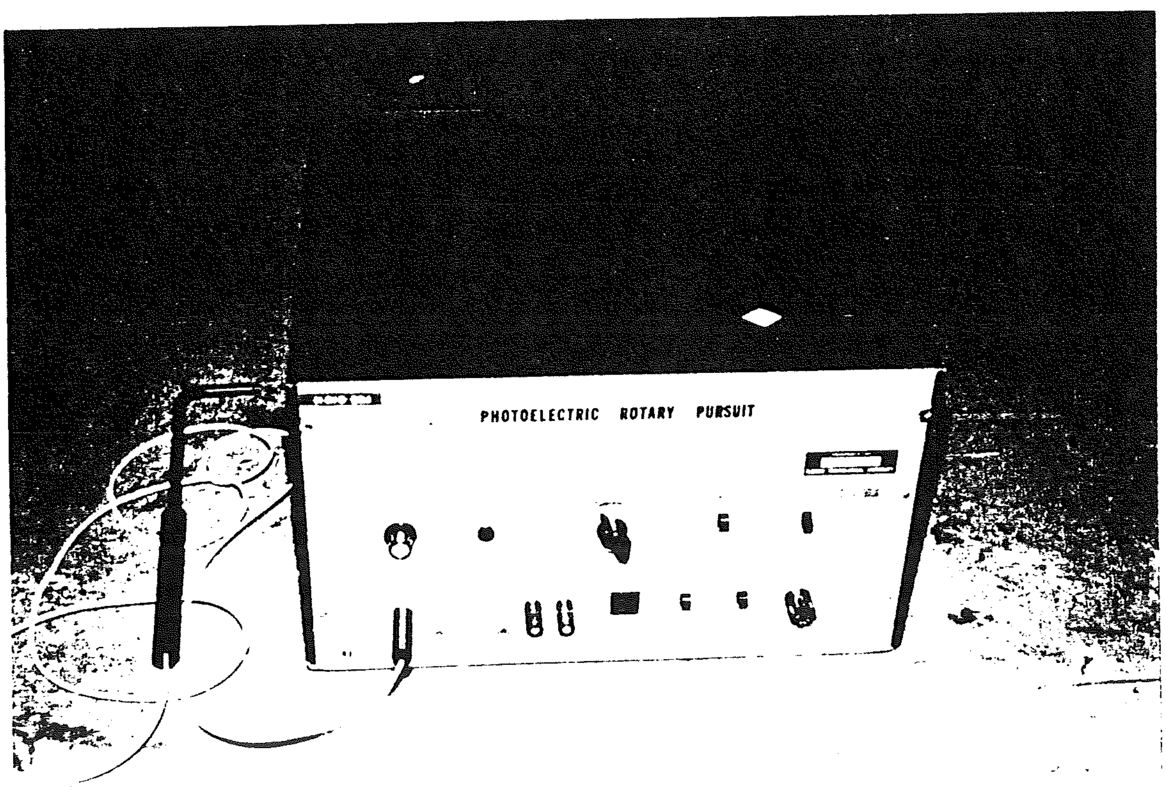



Figure 8. Photoelectric Rotary Pursuit and Stylus

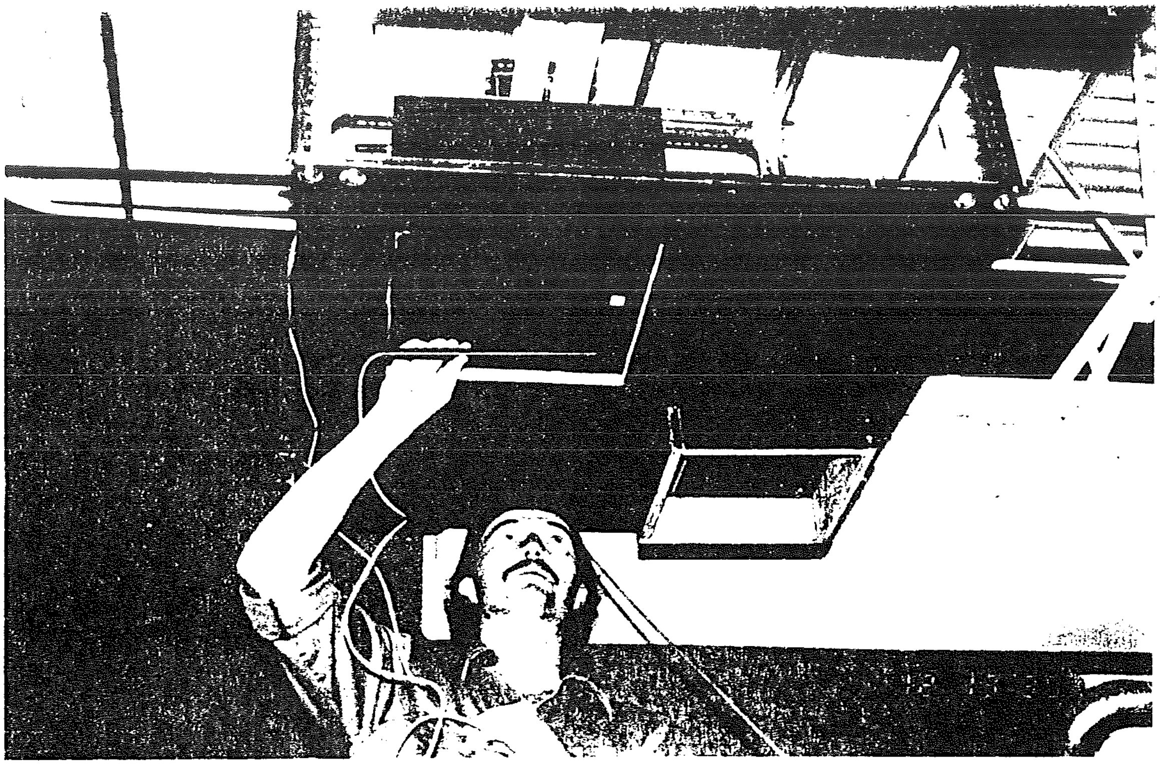


Figure 9. Subject Performing Tracking Task

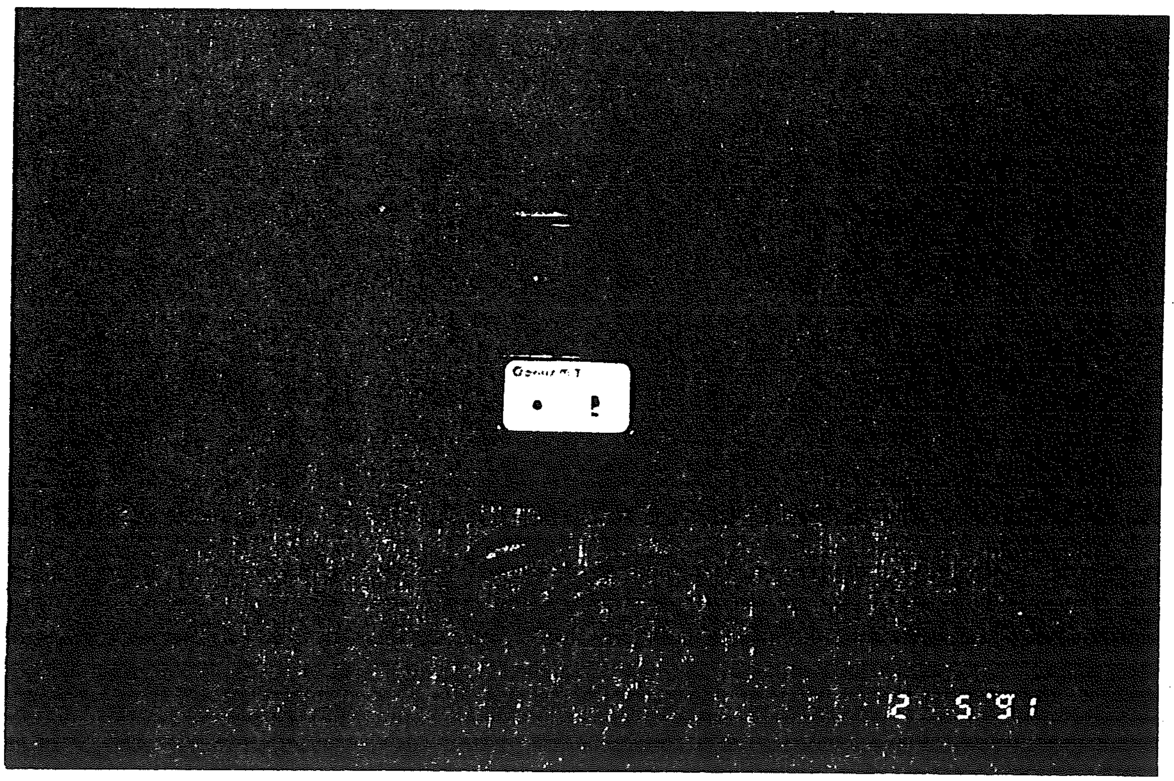


Figure 10. Digital Stop Clock

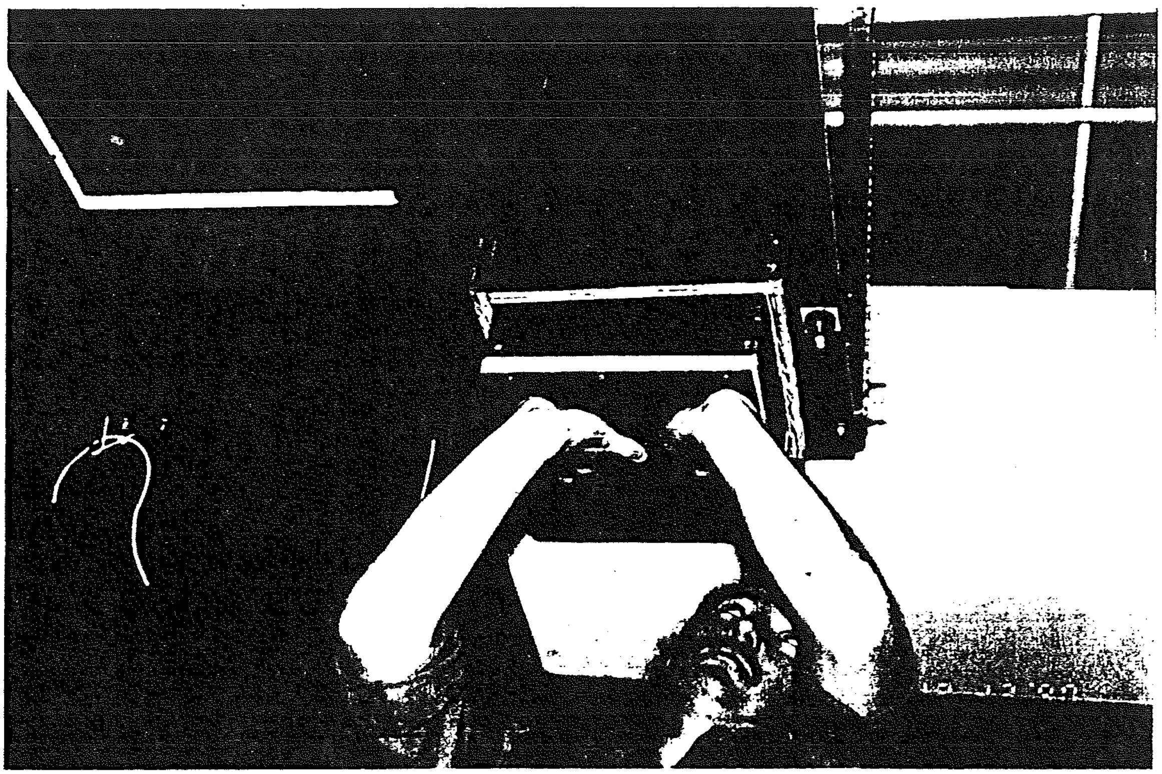


Figure 11. Subject Performing Weighted Overhead Task

### 3.4 Experimental Procedure

During the experiment the performance and body discomfort of tile technicians were measured in an effort to contrast the level of performance and comfort associated with both the typical standing overhead working position and the semi-reclined and supported position offered by the ergonomic seat.

Five subjects were recruited from the tile technician population at KSC. They were fully instructed as to the nature and purpose of the experimental evaluation and encouraged to perform the processes at their usual level of effort and rate. The technicians were satisfactorily compensated for their time and efforts.

The experiment involved five subjects and four processes; two tile repair and maintenance simulations and two general application tasks. The whole experiment was replicated once in order to reduce the experimental error.The subjects performed the four processes in two working positions; standing and seated. The experiment required four separate visits from each subject for a time duration of approximately 1.5-2 hours each. Each visit was virtually the same except for the position in which the processes were completed. Each subject completed all four processes on each visit. During the performance of each process, the work performance and body discomfort of each subject was measured. The parameters initially measured were task completion time, endurance time, task accuracy, and body discomfort.

The experimental procedure was as follows:

1. During the initial visit, the full objectives of the study and the experimental procedures were presented to the subjects in detail.
2. Randomly choose the overhead working position for each experimental run, standing or seated.
3. Instruct the subject to obtain the necessary amount of RTV for P-601, Installation of Pillow (Alumina) Gap Fillers from the laboratory mixing area.
4. Instruct the subject when to begin performing the first process, P-601 . Simultaneously, time, video tape, and observe the technician throughout the process.
5. Instruct the subject to complete the comfort survey upon final completion of P-301.
6. The subject will be asked to obtain the necessary amount of RTV for the second process P-301, Tile Installation.
7. Instruct the subject when to begin performing the second process, P-301 . Simultaneously, time, video tape, and observe the subject throughout the process.
8. Again, instruct the subject to complete the comfort survey upon final completion of P-301.
9. Instruct the subject to practice on the Rotary Pursuit Task for 5 minutes.
10. Instruct the subject to rest for 5 minutes.
11. Instruct the subject when to begin performing the Rotary Pursuit Task.
12. Instruct the subject to stop the pursuit task after 10 minutes. Record the readings on the time-on-target clock and the revolution counter.

13. Again, ask the subject to complete the comfort survey.
14. Instruct the subject to rest for 5 minutes.
15. Instruct the subject when to pick up the weighted box. Record the amount of time it takes to position the box within the cavity.
16. Carefully monitor the light indicator for contact. Record the endurance time of the subject.
17. Ask the subject to again complete a comfort survey.
18. The subject will asked for any comments upon completion of the entire experimental evaluation is over.

## 4.0 Results and Findings

The results of the experimental evaluation revealed that ergonomically designed workseat improves the work performance and provide body comfort during overhead operations especially for long duration activities. More specifically, the following summarize the evaluation results.

1. The seat dimensions were suitable for the conduct of the majority of operations except the lack of head and neck mobility offered by the workseat. However, the original workseat design include the adjustable headrest which was not implemented in the prototype due to cost constraints.

2. The worker's endurance time was significantly increased when the workseat was used. There was an average of 63 percent increase in endurance time as shown in Figure 12.

3. Task accuracy was significantly increased as shown in Figure 13 when the workseat was used. This reflects directly on the quality of work.

4. There was no significant difference, with and without workseat in the task completion time. This result is shown in Figure 14. This may be due to relatively short time duration required to complete the experimental tasks. However, when coupled with the large differences in endurance time, there will be a significant difference in task completion times over the course of long work hours.

5. The workseat greatly reduced worker's body discomfort caused by overhead positions. In some specific body parts such as lower legs and thigh, the body discomfort was eliminated. Specific body discomfort associated with each posture is shown in Figure 15.

Based on the above mentioned findings, it is concluded that the ergonomically designed workseat is effective in improving the productivity of tile technicians and in reducing their body fatigue.

The tile technicians' general comments were also compiled during the use of workseat. The following are some comments, which would affect the prototype buildup, shared by most of tile technicians during the use of workseat.

1. There was not enough clean work area, tools and equipment storage, and waste container. A tool "tray" or some other means for the operator to have access to the tools without changing position is necessary.

2. The technicians concerned over dripping RTV and other chemicals as well as falling debris. A protection such as a face shield is desirable.

3. There is a need for information access while work is being done for some operations as well as exchanging information with floor crew.

(4) There is a need for an arm rest in each side.

The above mentioned comments and suggestions were implemented in second detailed workstand design.

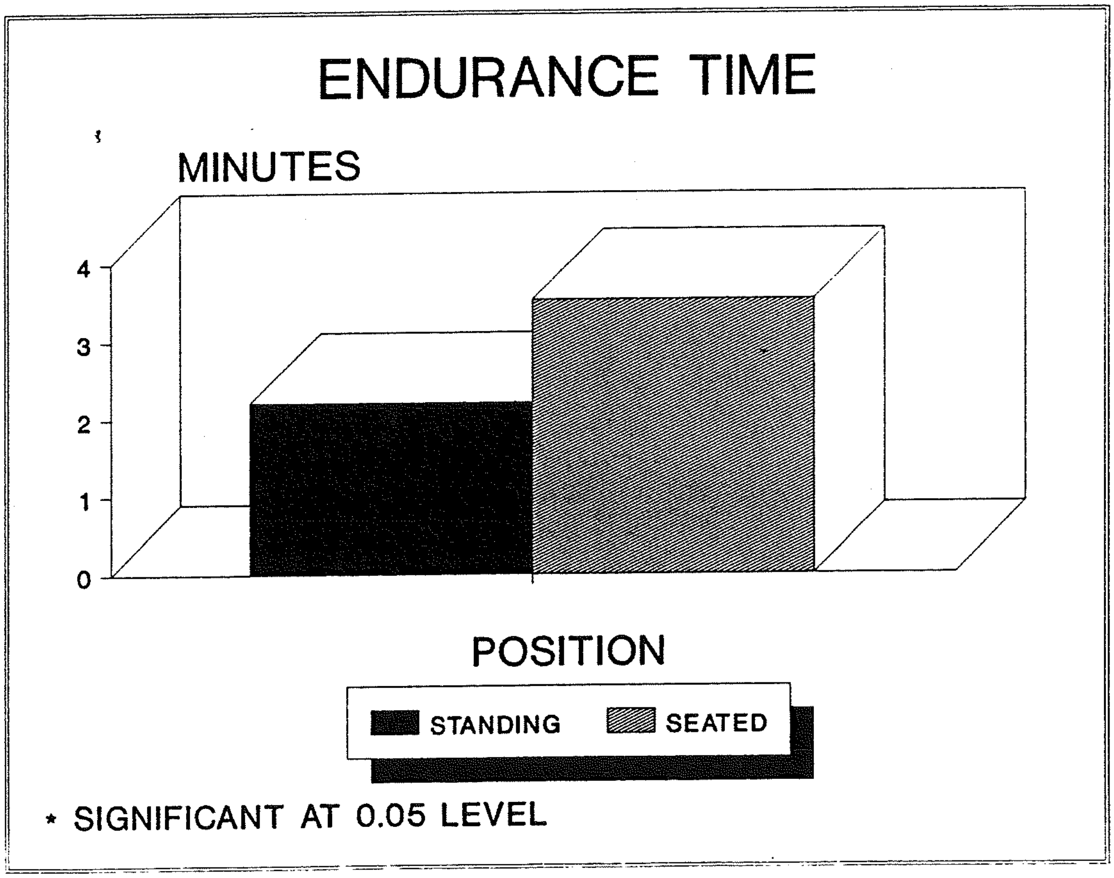



Figure 12. Endurance Time

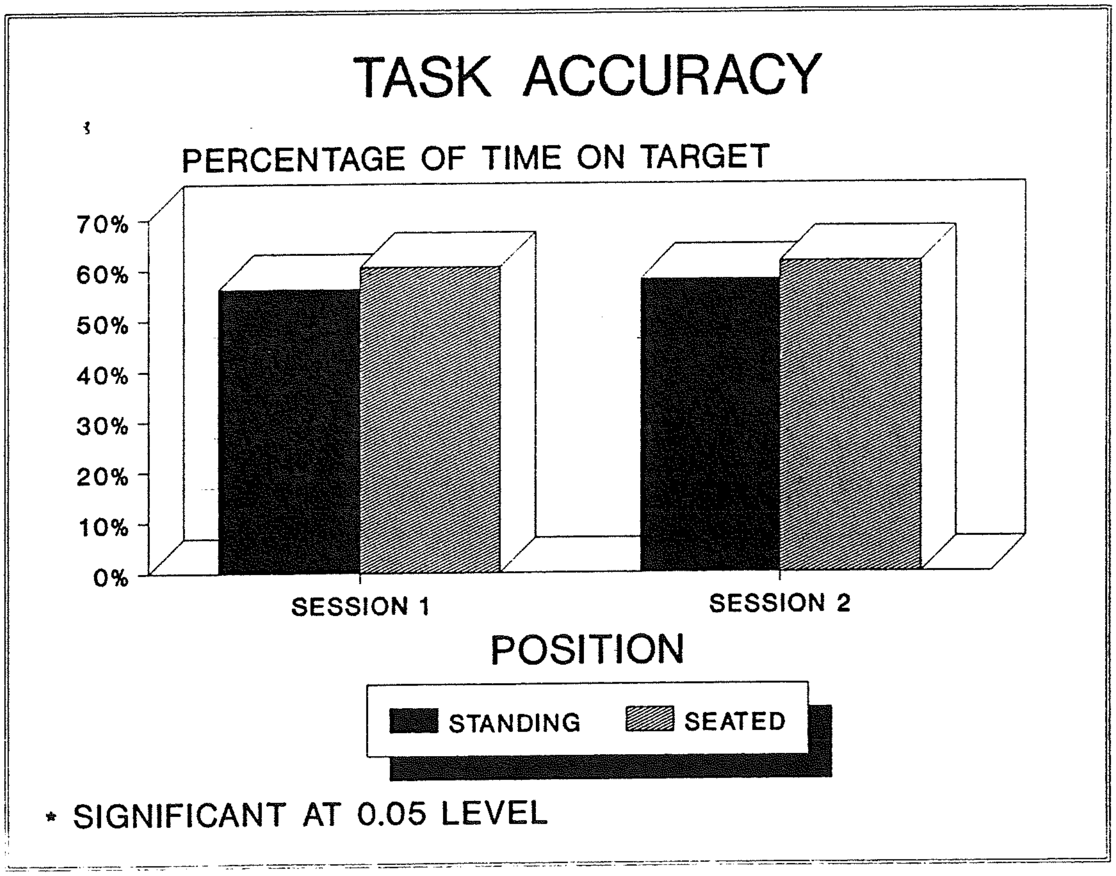



Figure 13. Task Accuracy

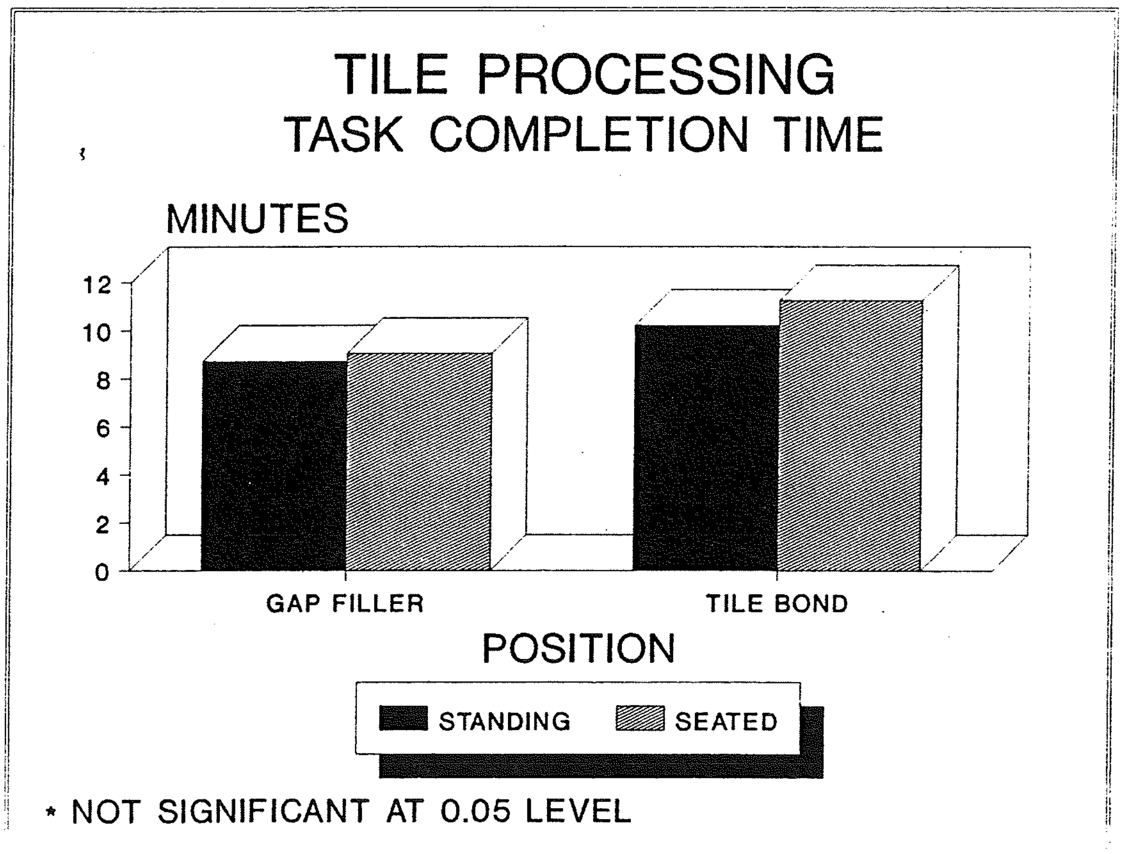
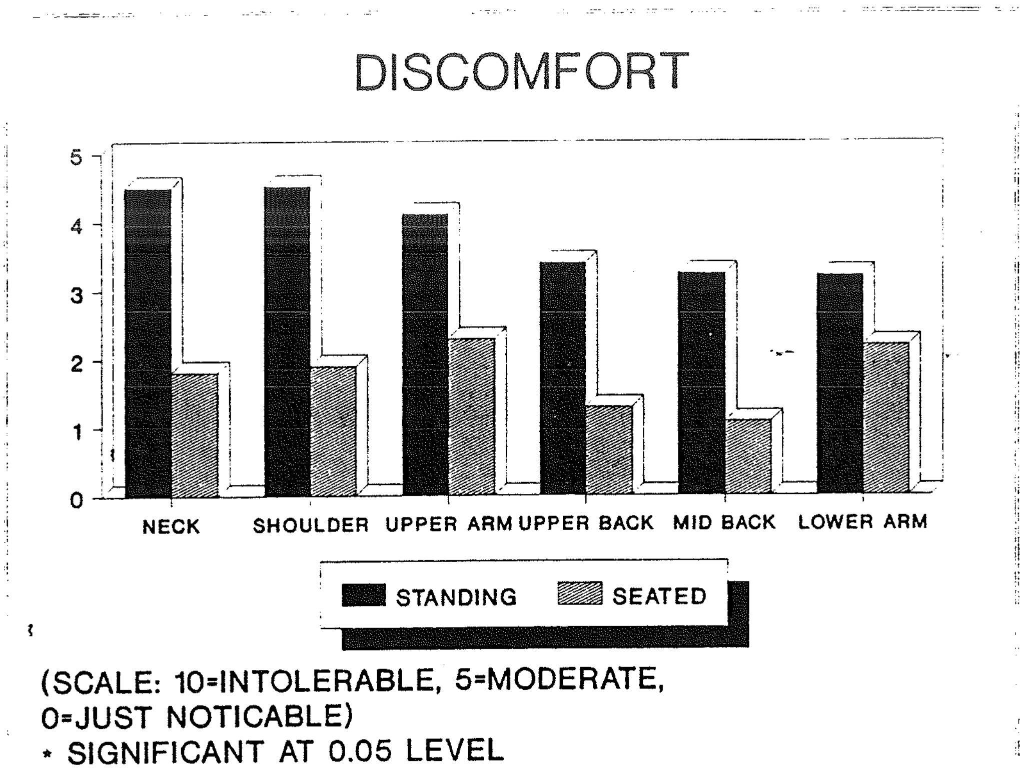



Figure 14. Task Completion Time



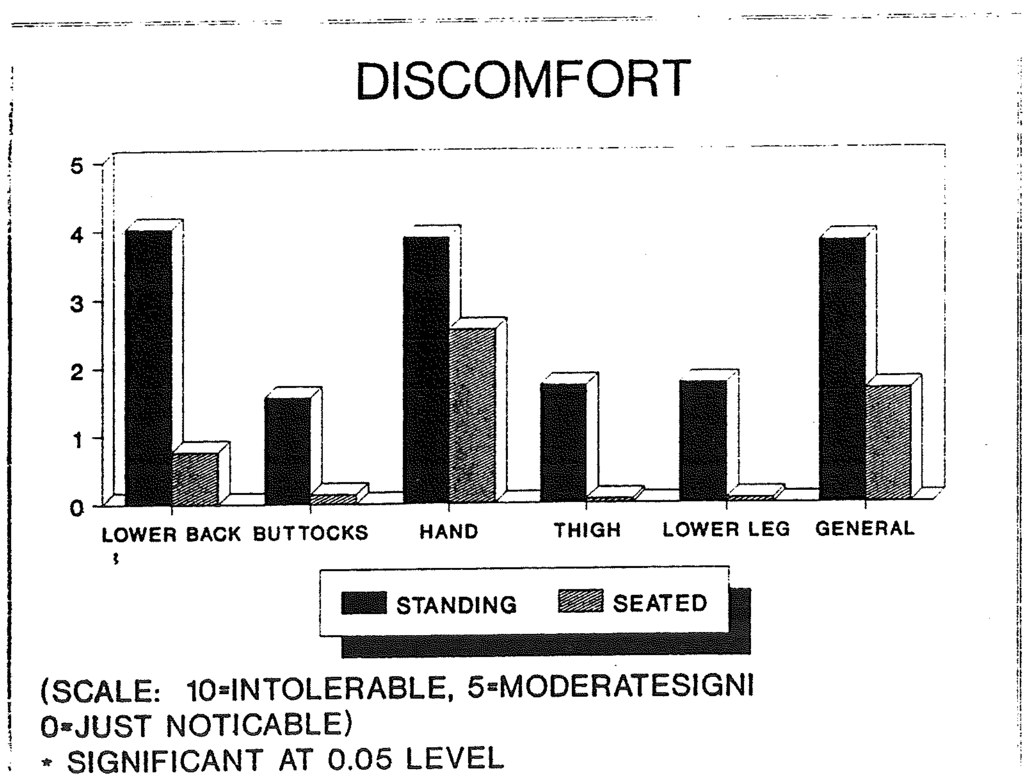




Figure 15. Body Part Discomfort

# Appendix II

## Voice Data Entry

UNIVERSITY OF CENTRAL FLORIDA/KSC
COOPERATIVE AGREEMENT

PROJECT #6

PRODUCTIVITY TECHNIQUES

# VOICE DATA ENTRY COMPONENT

# PHASE II - REPORT

SPRING 1991

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## 1.0 INTRODUCTION

Voice Data Entry (VDE) is an evolving technology that converts natural speech to computer data through voice recognition components and computer data to speech/voice output through a speech synthesis component. A typical voice recognition system allows the user to enter data, issue commands, and perform transactions by verbally entering information using natural, conversational speech. Manufacturers of state-of-the-art recognition hardware claim that vocabularies of hundreds of words can be recognized with recognition rates of 99 percent. The recognition process may or may not be user dependent. Speech synthesis could allow a computer to verbally prompt a user during an application procedure.

Previous efforts with respect to tile processing include a pilot project by Lockheed Space Systems and Stanford University, California, through the SIORA (Space Integration & Operations Research Applications) program that allowed technicians to verbally enter numeric step and gap measurements as they pertain to P-310 (tile step and gap measurement). The University of Central Florida, through the PHASE I COOP agreement program, developed the training and implementation strategy for the Lockheed pilot project (refer to PHASE I interim report). The current objectives as stated in February 1990 statement of work include:

1. STUDY THE FEASIBILITY OF A MICROCOMPUTER BASED VDE SYSTEM -- Problems identified in the step and gap application indicated that the step and gap process was not the most viable candidate for VDE. Advances in the field of microcomputers indicate that it may be feasible to use a microcomputer based system. This use will be investigated by UCF.

2. DESIGN AND CARRY ON AN EXPERIMENT -- Through experimentation, we can make an assessment of the feasibility of using microcomputer based speech recognition technology in orbiter processing activities.

3. STUDY POSSIBLE PROBLEMS IN INTERFACING WITH KSC'S COMPUTER SYSTEM (i.e., SPDMS II) -- KSC is currently developing/converting many of its systems to be computer based. SPDMS II (Orbiter Processing Data Management System II) will be the computer platform for these efforts. It is envisioned that all systems deployed at KSC will share this platform. If VDE becomes feasible as a computer communication medium, it is important to study any interfacing problems with SPDMS II.

4. EXPLORE NEW APPLICATIONS OF VDE -- UCF is striving to obtain a familiarity with VDE that can only come from a prototyping effort. While an initial effort may center on the tile processing environment, we also recognize that the TPS is only a fraction of the systems involved with orbiter processing. Future endeavor's may extend to other facets of orbiter processing. A systematic procedure for identifying processes amiable to VDE will be developed.

## 2.0 KSC POTENTIAL APPLICATIONS

### 2.1 GENERAL

Following are some of the job characteristics which would qualify a job to be considered for VDE:

- TASKS REQUIRING COMMUNICATION WITH A COMPUTER - Since VDE is a means of communicating with the computer, any job which requires such communication as part of its procedure may be considered for VDE application. Other factors such as the environment, the speed of communication, and the reliability need to be assessed as well.
- FREE HAND ENVIRONMENT REQUIRED OR DESIRABLE - When a job requires that manual labor of some sort be interrupted to write down or key in data, then VDE may be considered as an alternate form of computer interaction.
- DATA ENTRY REQUIRED IN PERFORMANCE OF TASK - When large amounts of repetitive data are to be entered to a data base, a reliable voice data entry system can make substantial savings in terms of time thus resulting in an increase in productivity. Benefits may be even greater if the operator is not skilled in the use of the keyboard or that the keyboard is not designed or positioned properly for data entry.
- A LIMITED AND CONSISTENT JOB TASK VOCABULARY - Voice data entry systems are more reliable and efficient if they deal with limited vocabularies. Jobs with limited vocabularies, or those that can be redesigned to use a limited vocabulary may be eligible for VDE.
- STABLE MANPOWER, AS VOICE RECOGNITION REQUIRES TRAINING - Studies have shown that training the system for specific users can be a limiting factor in the VDE application. Once the system is trained for a specific user, it is in fact faster and more reliable than the user independent systems.

A general assessment of the tile processing environment was accomplished via direct observation of orbiter processing operations, and interviews with OPF personnel. The results of this initial assessment indicate that three areas exist that could benefit from VDE technology. They are:

— STEP AND GAP MEASUREMENT (P-310)
— TILE IDENTIFICATION
— PROBLEM REPORTING

It should be pointed out here that the effort of identifying jobs at KSC which may benefit from VDE is a continuous task along this project. Efforts may be extended toward redesigning some of the identified jobs to eliminate redundancies, thus making them compatible with VDE. The three areas identified here were determined based on the general characteristics listed above and were meant to provide us with a specimen for a

laboratory experiment for a typical application at KSC.

## 2.2 P-310 (Step and Gap Measurement)

Although no effort was expended on further investigation of P-310, as previous efforts from other agencies have documented VDE's applicability in that area, several points are worth mentioning as to the problems associated with the P-310 VDE pilot project:

CONNECTION TO VOICE RECOGNIZER — Users communicated with the International Voice Products recognizer via hardwired connection. This restricted the user to a limited radius around the recognition hardware, in addition to possibly violating KSC policy with respect to cables in the OPF.

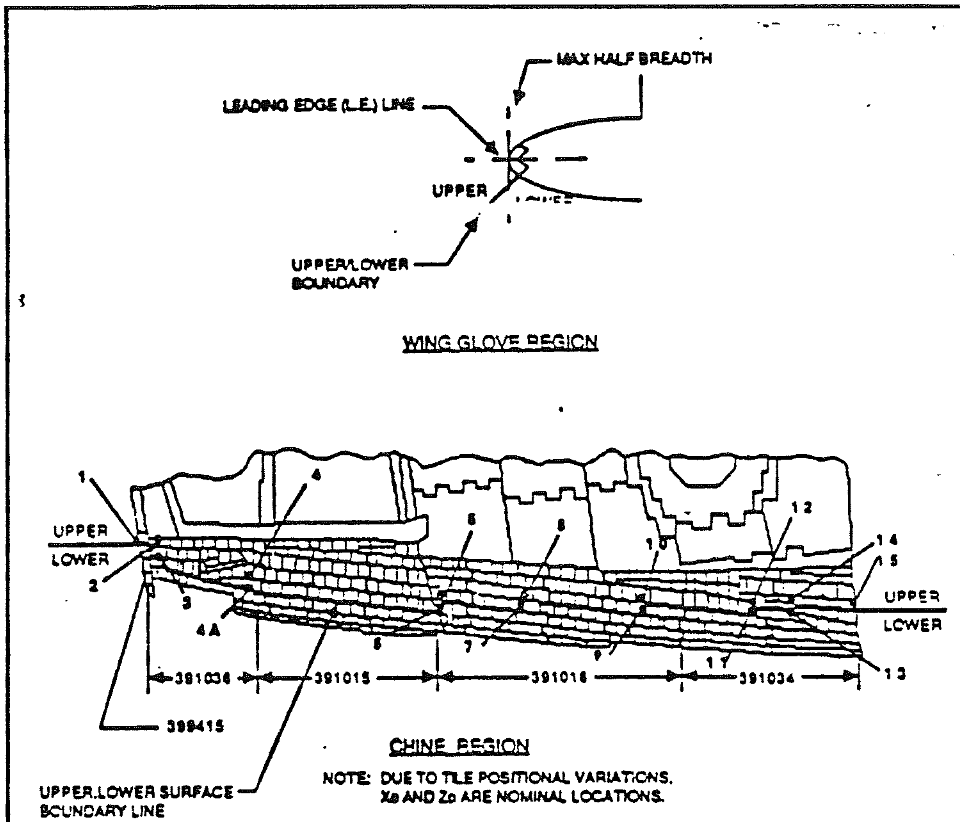
TRAINING TIME — While essentially all voice recognizers must be trained to recognize the users voice, questions were raised concerning the amount of training time necessary compared to the tile technician turn-over rate. With respect to system acceptability, some resistance by technicians and supervisors to the system has been noticed. Consideration to human engineering and the technician/supervisor acceptability to new technology is warranted for successful application.

COMPUTER PLATFORM — The SIORA pilot project was based on an International Voice Products recognizer connected to a MicroVAX located in the mezzanine between the two hi-bays. This system is not supported in the OPF environment. Future VDE configurations would have to interface with the SPDMS II platform which will be based on the IBM PS/2.

LASER STEP AND GAP TOOL — Recording measurements by VDE did not eliminate the most prevalent failure mode involved with P-310 -- the actual measurement itself. The laser step and gap tool can accurately record measurements, then send them directly to a database.

## 2.3 TILE IDENTIFICATION

2.3.1 CURRENT PROCEDURE — When inspecting or repairing tiles, it is critical to determine in which region a tile belongs. The orbiter is divided into several regions as shown in figure 1. Tile identification is a real concern to NASA and Lockheed engineers who must determine a tile location on the orbiter.




| PT | Xo | Zo | PT | Xo | Zo |
|---|---|---|---|---|---|
| 1 | 259.14 | 325.34 | 8 | 440.00 | 306.89 |
| 2 | 268.01 | 325.88 | 9 | 485.00 | 301.78 |
| 3 | 298.08 | 320.73 | 10 | 485.00 | [illegible] |
| 4 | 310.27 | 312.03 | 11 | 534.50 | 302.37 |
| 4A | 310.27 | 311.54 | 12 | 534.50 | [illegible] |
| 5 | 397.00 | 302.75 | 13 | 554.00 | 303.97 |
| 6 | 397.00 | 307.97 | 14 | 554.00 | 308.50 |
| 7 | 440.00 | 301.55 | 15 | 578.44 | 303.70 |

**Figure 1 – Sample region of orbiter surface.**

The current process involves visual reference to drawings to determine a tile's region. While tiles toward the center of the region are easy to identify, tiles which lie on or near the border between two regions may cause difficulty. If the technician cannot clearly discern to which region a tile belongs, he must consult with a Rockwell engineer who in turn consults a computer database which contains location data on each tile. The process relies heavily on technician experience and familiarity with tile regions. Moreover, this task can be a frustrating and time consuming process and subject to error. For better quality of work and reliable identification, consultation with the data base may be essential while the technician or engineer is in a remote location with respect to the computer terminal. A VDE system may be of value in such situations.

2.3.2 PROPOSED PROCEDURE — The proposed procedure would connect the engineer directly to a tile region database. If consultation is to occur, the engineer need only speak the tiles identification number and be given a voice synthesized computer response consisting of the tiles location, along with any other pertinent data that could be supplied by the database. One advantage for such an application is that the vocabulary to be used may be limited to character by character voice data entry, which may be user independent (i.e., no training for system is required).

2.3.3 EXPECTED GAIN IN PRODUCTIVITY — Although time savings could be realized in certain cases, indirect gains would be immediately obtained in terms of quality of data such as instant tile location. For proper quantification of expected gain in productivity, all jobs requiring tile identification and or data base query while not in position to use a computer terminal may have to be surveyed and the use of VDE be assessed and compared to the current procedure.

## 2.4 PROBLEM REPORTING

### 2.4.1 CURRENT SYSTEM

Problem Reporting (PR) with respect to the TPS is a procedure to document problems identified with the orbiter's protective tiles. Examples of problems include a tile that is chipped, gouged, debonded, or missing. These are problems that will require corrective action. The PR documents the exact nature of the discrepancy, and becomes the cover sheet for a Work Authorizing Document (WAD) that will eventually include the engineers disposition report, which is a detailed description of the steps needed to correct the problem.

The basic flow of problem reporting and the PR document production can be summarized as seen in figure 2 below:

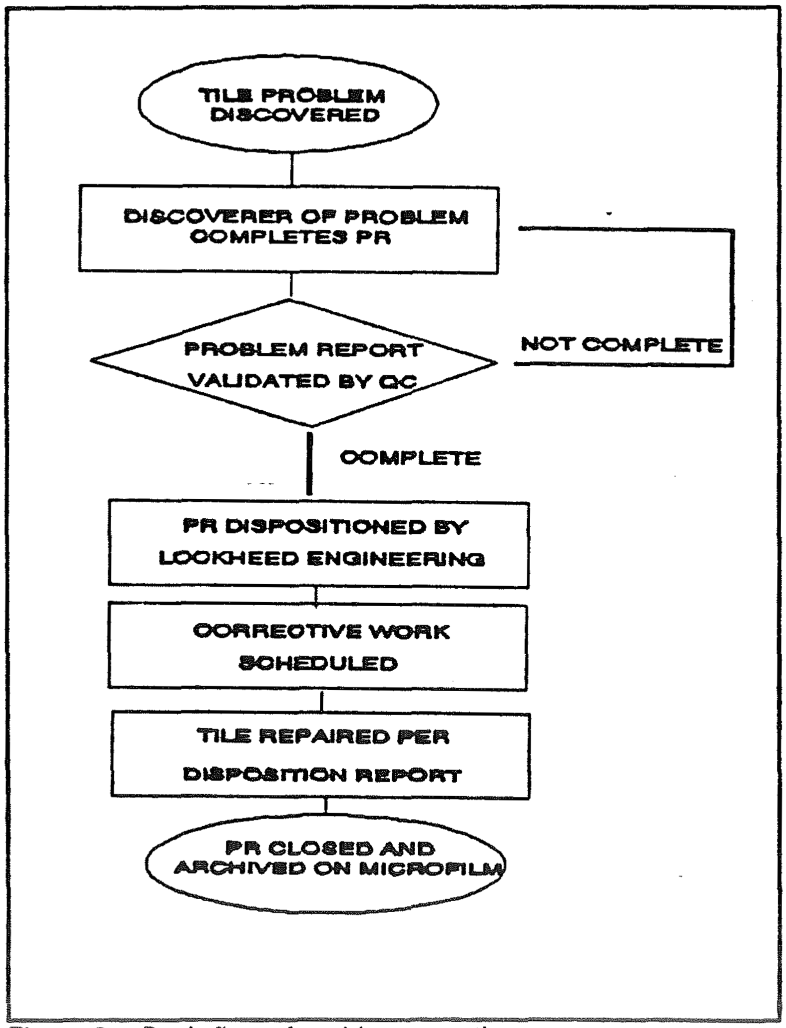



Figure 2 -- Basic flow of problem reporting.

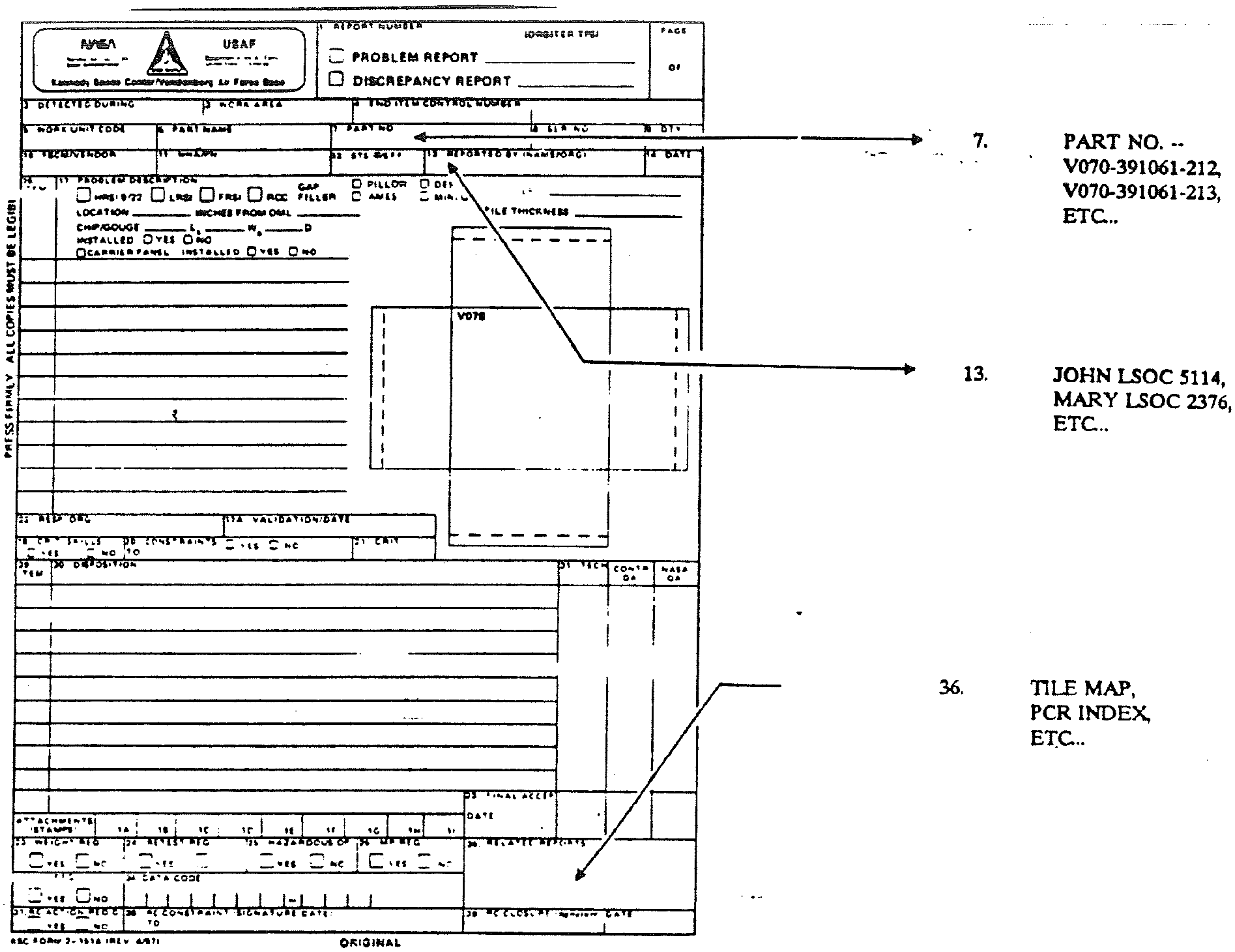
## 2.4.1 CURRENT SYSTEM (Cont.)

Problems on the orbiter can be identified by any technician. Usually, a team of quality supervisors inspect the orbiter upon landing at KSC. The process is usually done in the OPF environment, however a pre-inspection may take place in California if the orbiter lands there. Each QC inspector (technician) is responsible for ceratin section of the orbiter. The actual process of identifying anomalies is done by observation. Once a problem is identified, the inspector completes a problem report form (see figure 3). In a typical process, the inspector may have to consult technical documentation or computer data bases for proper completion of the report. Some of the "vocabulary" used in the report is standard such as tile number, while other areas are not standard, especially the problem assessment. It is believed, though, that there are enough problem reports available on microfilm which if compiled may produce a standard vocabulary to cover the majority of the problems. The PR is then validated by a QC inspector who ensures that the report is complete and has enough information to assess the problem. The PR is then dispositioned by a Lockheed engineer, who details the work required, thus producing a Work Authorizing Document (WAD). Corrective work is then scheduled in such a way as not to conflict with other maintenance work be performed. Corrective work is then performed according to the directions given in the WAD. Corrective work performed by the technician is then "bought off" by the quality supervisor. Finally, the PR is signed by representatives from all affected areas and the completed WAD, which can be quite bulky at this point, is sent for archiving on microfilm.

## 2.4.2 PROPOSED SYSTEM -- PROBLEM REPORTING WITH VDE

Developing the necessary grammar definition file to recognize PR data would be facilitated by the programming structure and features of a voice development software. By categorizing each block of the PR as its own grammar, the possible responses can be limited to only that which is legal within that particular block. A typical TPS PR, along with its sample grammar definition file, is shown in figure 3 to illustrate this point.

## 2.4.2 PROPOSED SYSTEM -- PROBLEM REPORTING WITH VDE (Cont.)




With the exception of blocks 17 and 30, all blocks have a relatively limited vocabulary that can be assumed to be well within the capabilities of any VDE system. Blocks 17 and 30, however, involve describing the exact nature of the problem in engineering terminology. This presents a challenge to developing a VDE application for problem reporting. The possible responses when describing tile damage are numerous, however a modified PR procedure may limit the vocabulary used and put it within current VDE capability. A more thorough study is essential for this application.

### 2.4.3 PROBLEM REPORTING WITH VDE

In trying to determine the feasibility of this evolving technology as it applies to tile processing, it becomes necessary to consider the functional areas involved and how they can integrate with VDE technology.

The functional areas that have been identified with respect to tile processing are:

- RELIABILITY - Errors in PR's can be time consuming and costly, particularly when the wrong tile is worked or pulled. Several failure modes for tile processing have been identified. They are:

  — TECHNICIAN MISIDENTIFIES ANOMALOUS TILE -- EFFECT: POSSIBLE REPAIR OF WRONG TILE.

  — TECHNICIAN MISIDENTIFIES ANOMALOUS TILE, WRITES UP PR WITH INCORRECT TILE ID, AND IMMEDIATELY REPAIRS DAMAGED TILE -- EFFECT: LOSS OF TRACEABILITY

  — TECHNICIAN INCORRECTLY TRANSPOSES PR DATA FROM ONE FORM TO THE NEXT DUE TO THE ILLEGIBILITY OF THE ORIGINAL PR -- EFFECT: A HOST OF POSSIBLE ERRORS, SUCH AS DELAY OF WORK, INCORRECT REPAIR, ETC..

  VDE can reduce the errors associated with tile identification and recording by providing the technician with the ability to simultaneously view and report the damage on the anomalous tile. Data entered by voice can then be instantly verified through synthesized voice response.

- HUMAN FACTORS - SPDMS II calls for PR data to be entered into a data base via IBM PS/2's acting as terminals for the mainframe computer. The primary means for communicating with computers is through the keyboard. This requires a certain level of typing proficiency if the data is to be entered in a timely and accurate manner. VDE provides an alternative to the keyboard by allowing spoken phrases to be sent to the computer just as if they had been typed on the keyboard. Further, the keyboard requires that the technician be seated in front of the terminal when entering data. This offers little improvement over the manual method as technicians must still record data manually when under the orbiter and then return to the terminal to input the data. A wireless voice link with the computer would eliminate the interim step of recording data from the field so as to return to the terminal. Technicians could enter the data while looking at the problem under the orbiter.

- CONFIGURATION MANAGEMENT - Tile locations on the orbiter are maintained via drawings (or most recently via CAD software) that the technician must refer to if in doubt about the identity of a certain tile. Misidentification of tiles could be further avoided if an on-line expert system were available to assist with, and/or verify, tile identification.

## 3.0 INTERFACING WITH KSC's COMPUTER SYSTEM

### 3.1 SPDMS II

SPDMS II, Orbiter Processing Management System II, is a new computer work control system that is being implemented by Lockheed. It will control the Orbiter processing operations by:

- CONTROLLING WORK PACKAGE PRODUCTION AT THE TEST, ASSEMBLY, AND INSPECTION RECORD (TAIR) STATIONS
- CONTROLLING FACILITY RESOURCES (TECHNICIANS, ENGINEERS, SAFETY PERSONNEL, MATERIALS, AND EQUIPMENT)
- CONTROLLING PROBLEM REPORT (PR), INTERIM PROBLEM REPORT (IPR), TEST PREPARATION SHEET (TPS), AND DEVIATION (DEV) PROCESSING

With respect to the third bullet, that of controlling problem reports, VDE (Voice Data Entry) can have a positive effect on interactions between technicians and computers.

SPDMS II, which has yet to see full implementation, will improve orbiter processing efficiency by:

— RELEASING ONLY "WORKABLE" PACKAGES

— DECREASING PAPERWORK

— IMPROVING ACCURACY OF RECORDS

— IMPROVING WORK SCHEDULING

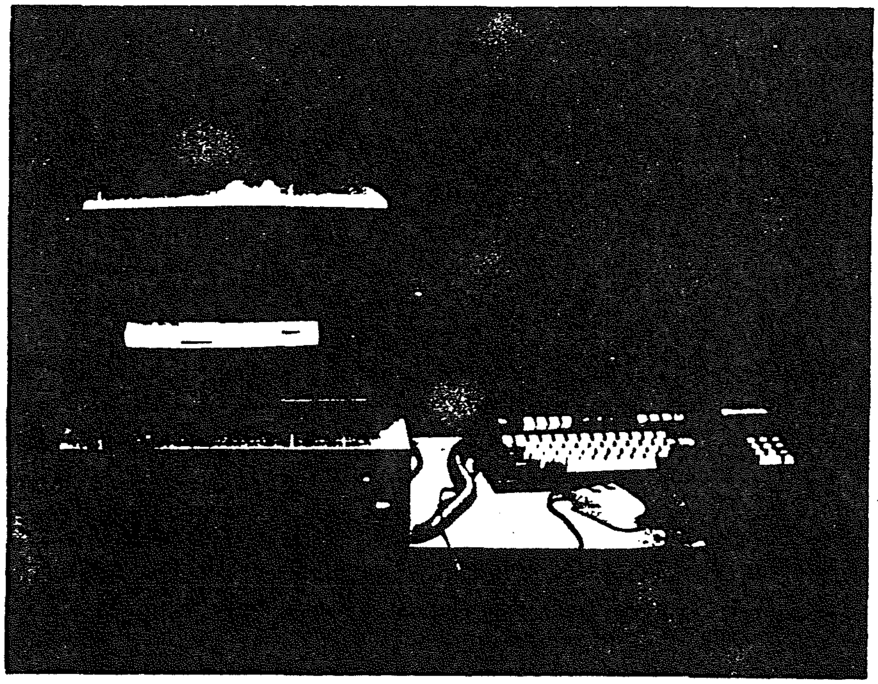
— IMPROVE WORK ACCOUNTABILITY

— PROVIDING NEAR REAL-TIME STATUS

VDE can impact these goals by offering an alternative means of interacting with the computer. Since SPDMS II will involve installing computers on the OPF floor, VDE can play a role in enhancing the man and machine interaction.

3.1 SPDMS II (Cont.)

SPDMS II will be comprised of computer workstations located in all areas of KSC including the HI-BAY floor. These workstations will be composed of IBM 7561 industrial version PS/2's operating under an OS/2 multitasking environment. These computers will have 105 Megabyte hard drives, and 16 Megabytes of RAM. Several computers will be networked together via token ring, each having the ability to interface with NASA's IBM 3090 mainframe computer. The IBM 7561 PS/2 is pictured below:



3.2 INTERFACING VDE WITH SPDMS II

The Verbex voice recognizer, can be interfaced to NASA's proposed SPDMS II computer system. The majority if VDE systems can easily be interfaced with SPDMS II's network. The recognition and synthesis process required in any application can be handled at the workstation level.

Fortunately, the Verbex hardware can be connected to the above system with little or no modification. For most applications, such as problem reporting, the Verbex would be communicating directly with the PS/2 which would be running the problem report module software. The verbex can, however, communicate with the IBM 3090 as well due to the fact that both the Verbex and the PS/2's use VT-100 terminal emulation. This was proven in the UCF laboratory as explained later. As currently envisioned, the Verbex would be connected to the PS/2's via COM-Port cable.

In this configuration, the Verbex functions as an extension of the keyboard, allowing the user to send data by "speaking" to the computer via headset, just as if he were typing the data manually.

The Verbex receives voice patterns from the user by a microphone which can be hardwired to the unit or sent by radio waves from a wireless transmission unit. The hardwired approach produces the greatest accuracy, but it requires the user be seated in front of the computer when speaking as shown below:

The wireless approach, which is still under study for feasibility, outfits the user with a headset and a portable transmitter/receiver which allows the user to converse with the computer hands free. While this approach allows for the greatest mobility of the user, interference from metal scaffolding, as well as DOD limitations on transmitters within the OPF, may prohibit its use in the current context of applicability.

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## 4.0 EXPERIMENTAL EVALUATION OF VDE HARDWARE

### 4.1 INTRODUCTION:

UCF has acquired the VERBEX SERIES 5000 voice recognizer for the purposes of determining the systems general capabilities. Since the operational environment at NASA presents special problems to the wireless voice recognition process, an experiment was conducted in the UCF lab to determine a baseline for operational characteristics of the VERBEX system.

UCF's VDE work is oriented towards determining OPF tasks compatible with VDE. An element of this compatibility is that of a hands-free working environment.

### 4.2 THE PROBLEM:

Future evaluation efforts of potential KSC tasks will require a knowledge of the capabilities/limitations of the current state-of-the-art voice recognition equipment.

One of the task characteristics identified as making a job compatible with VDE is that of a hands-free working environment. While a hardwired approach can attain this goal, the user is restricted to an area around the hardware not exceeding the length of the cable. The user can be freed from this restriction if a wireless approach is utilized. This would entail outfitting the user with a portable transmitter/receiver that would communicate with a base unit located next to the recognition hardware. To test the feasibility of this approach, UCF has also procured the COMMUNICATIONS APPLIED TECHNOLOGY RS111 base radio assembly and the QB-1C mobile transmitter/receiver for testing purposes with the VERBEX SERIES 5000 recognizer.

### 4.3 EQUIPMENT NEEDED FOR PROPOSED RESEARCH:

Previous efforts with respect to VDE at KSC were based on the International Voice Products continuous voice recognizer. This system served as the platform for the P-310 voice application prototype. While it performed adequately, doubts about its ability to handle more complex applications were raised in light of its limited memory (100 words in a single application only). UCF choose not to select the same system but rather a more powerful one with higher vocabulary capacity.

The VERBEX SERIES 5000 is a continuous speech recognition system from Verbex Voice Systems, Inc.. The model that UCF acquired has a theoretical upper limit of 600 to 800 words maximum, but only 80 words can be active for recognition at any one time. In order to utilize the full power of the system, multiple vocabularies must be used. Users communicate with recognizer via hardwired headset or optional radio communication device. The optional radio device is described next.

The COMMUNICATIONS APPLIED TECHNOLOGY RS111 base radio assembly and the QB-1C mobile transmitter/receiver allow the user to communicate with the recognizer in a wireless vicinity. The crystal frequency controlled system broadcasts with 50 milliwatts of power. The microphone has a range of 200 - 4000 Hz within +/- 2 Db. *(NOTE: Experiment was conducted with equipment as received with no modifications.)*

## 4.4 SUBJECTS:

Two subjects, both male, were used. Data collected from the two subjects was analyzed separately and collectively.

## 4.5 EXPERIMENTAL METHODOLOGY:

Dependent and independent variables for this experiment were identified as follows:

### DEPENDENT VARIABLES:

- Phrases Recognized (after 1, 2 or 3 attempts)
- Phrases Presented

### INDEPENDENT VARIABLES:

- Distances from the base receiver
- Speaker

#### CONTROLLED VARIABLES:

- Obstacles between receiver and transmitter.
- Other radio frequency emitting devices (computers)
- Background noise
- Vocabulary complexity
- Number of recognizer training passes completed

The experiment that was conducted tested the operational characteristics of both the radio system and the voice recognizer. The first experiment was designed to test the responsiveness of the voice recognizer to the radio-system. This was accomplished by attempting wireless recognition at various ranges from the base unit. The following control conditions applied to the test:

- LINE OF SIGHT COMMUNICATION (NO OBSTACLES)
- TWO REPLICATIONS OF THE EXPERIMENT WITH SUBJECTS (SEPARATELY)
- LOW AND MID LEVEL VOCABULARY COMPLEXITY (SEPARATELY)
- 2 TRAINING PASSES

The following schematic indicates how the unit was tested. The recognizer and base receiver were placed at the end of a 250 foot hallway. The user then attempted recognition at the following distances: 0, 50, 125, 150 FEET. Each of these distances were tested with two vocabularies.

The first vocabulary had a complexity factor of 4%, while the second had a factor of 23%. *(Briefly, the system calculates a complexity factor for a vocabulary based on the speech data entry rate versus the data processing rate -- 100% complexity would just allow the recognizer to keep up with the speaker. Less than 100% the recognizer can more than keep up, but more than 100% the recognizer may not be able to keep up with the user in real time.)*

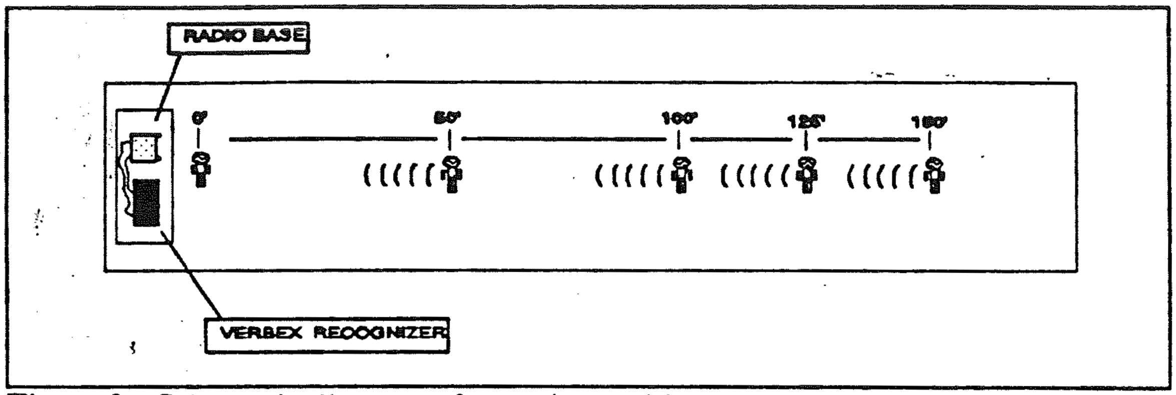


**Figure 3** - Schematic diagram of experimental layout.

For each vocabulary, and at each of the specified distances, the script phrases indicated in figure 2 were spoken:

| | |
|---|---|
| TILE IS BURNT | COATING IS BURNT |
| TILE IS CHIPPED | COATING IS CHIPPED |
| TILE IS CONTAMINATED | COATING IS CONTAMINATED |
| TILE IS DEBONDED | COATING IS DEBONDED |
| TILE IS MISSING | COATING IS MISSING |

**Figure 2** - Phrases to be spoken by the user.

The actual vocabularies used were designed in such a way that the only difference between them is the complexity level as perceived by the recognizer. The user attempted recognition with the same phrases as indicated in figure 2. The purposes of having a low and high complexity vocabulary to accomplish the same task is to determine how sensitive the system is to increased complexity. Both the low and high complexity vocabularies are indicated in figures 3 and 4.

```
;Vocabulary for experimental trial
!EXPVOC1=
#recognition
#grammar
.PR1

   .PR1=
    .OBJECT .PREP1 .ERROR_OF_OBJECT

   .OBJECT=
        TILE
        COATING

   .PREP1=
        IS

   .ERROR_OF_OBJECT=
        BURNT
        CHIPPED
        CONTAMINATED
        DEBONDED
        MISSING

#translation
< !!             ;no initiator string
```

**Figure 3** -- 4% complexity vocabulary.

```
;Experimental vocabulary
!EXPVOC2=
#recognition
#grammar
.PR1

    .PR1=
         TILE
         COATING
         IS
         BURNT
         CHIPPED
         CONTAMINATED
         DEBONDED
         MISSING
         DISCOLORED
         CHARRED

#translation
< !!             ; no initiator string
! !!             ; no separator
> !015           ; terminator is CR

#RES
#TE
```

**Figure 4** -- 23% complexity vocabulary.

An overall recognition percentage was calculated as follows:

$$RECOGNITION\% = \frac{\sum_{I=1}^{N} \frac{PHRASESRECOGNIZED}{PHRASESPRESENTED}}{N}$$

where N = (# phrases) * (# replications). The VERBEX recognizer was given three chances to recognize a phrase.

4.6 RESULTS:

The experiment yielded interesting results with respect to the capability of the overall system. Tabular data was collected, then processed to yield graphical information. For the initial run with the first subject, recognition rates scored in the eighty to ninety percent range, with recognition rates decreasing with distance. When the experiment was run with the second subject, however, poorer results were seen. Figure 7 indicates recognition rates for both subjects with respect to the 23% vocabulary complexities. With respect to the second subject, it is possible that two training passes were not sufficient to capture the more salient characteristics of his voice. Two More additional training passes were performed with the second subject. The results indicate that the cause of the unusually low recognition rate was most likely due to insufficient training. Following the two additional training passes, recognition rates for the second subject approached that of the first subject. The training problems associated with users not familiar with voice recognition technology has been documented in the manufacturer's literature.

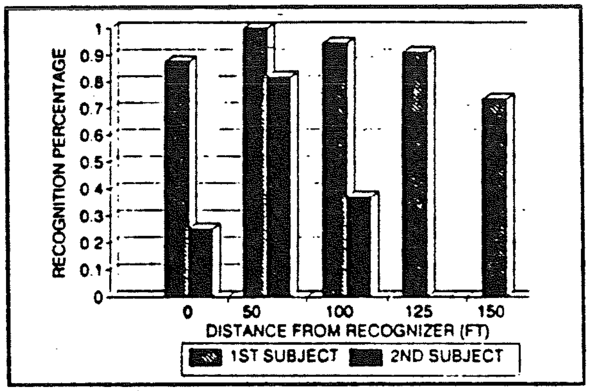


**FIGURE 5 - 23% complexity results before retraining second subject.**

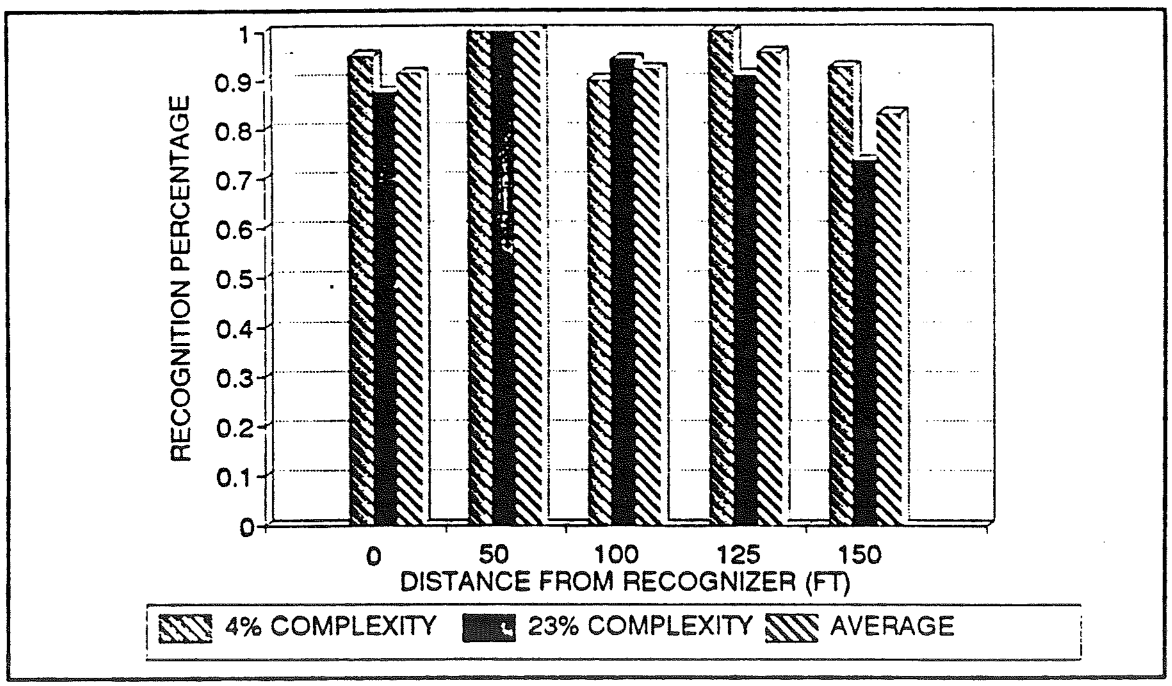


**Figure 6 -- Graphical results of experiment.**

The data indicates that vocabulary complexity has an effect on recognition ability, as does distance. From the data collected it may be said that:

- HIGHER COMPLEXITY YIELDS POORER RESULTS
- INCREASED DISTANCE FROM THE RECEIVER IMPEDES RECOGNITION
- OPTIMUM RECOGNITION DISTANCE UNDER EXPERIMENTAL CONDITIONS IS 50 FEET, WITH A MAXIMUM PRACTICAL DISTANCE OF 125 FEET (UNOBSTRUCTED)

# 5.0 DEVELOPMENT OF A MATRIX BASED PROCEDURE FOR THE DETERMINATION OF ORBITER PROCESSING TASK COMPATIBILITY WITH VOICE DATA ENTRY

## 5.1 INTRODUCTION

As demonstrated elsewhere in this report, Voice Data Entry (VDE) is a rapidly developing technology that has potential application in a wide variety of industrial situations. Possible applications in the orbiter processing "problem reporting" task have been illustrated in the project activities.

The bulk of the research to date in the field of VDE has been devoted to the development of equipment and software to enable VDE. Little work has been done to develop guidelines to enable an organization to systematically evaluate the tasks or processes it performs to allow an identification of those tasks that are most compatible with VDE. As pointed out by Hollingum and Cassford (1988) the basic speech recognition hardware and the software necessary to interface the speech hardware with the computer typically represents a relatively small part of the total cost, less than 30%, of the system. The remaining 70% is involved with interfacing the hardware and software with the on-going process. Careful selection of the processes is therefore necessary to ensure that VDE implementation costs do not become exorbitant.

Careful and systematic selection of tasks to be enhanced via VDE technology is important to ensure also that the benefits associated with the VDE implementation are maximized and that the impact of problems associated with the "early" or "learning curve" failures are minimized. One strategy, therefore, in selecting first tasks for VDE implementation is to pick simple non-critical tasks for first application. Another strategy, and one suggested by previous research on this project, is to introduce the new technology while simultaneously keeping the old techniques in place. Once the new technology is proven and the early failures are remedied, the older procedures can be phased out. Either of the above approaches is a useful initial approach for VDE implementation. Neither approach can be considered efficient for long-term use in the selection of tasks to be aided by VDE.

The guidelines currently available for selecting tasks are exemplified by those suggested by Hollingum and Cassford (1988) who point out that VDE applications are basically concerned with data capture. The VDE technology must be considered for application in a process in the same manner as, or as an alternative to, keyboard entry, bar-code reading, and magnetic strip reading. Factors that need to be considered in evaluating and deciding between these alternatives are typically presented in a list form such as that below:

- NEED TO HAVE EYES FREE FOR OTHER TASKS
- NEED TO HAVE HANDS FREE FOR OTHER TASKS
- NEED FOR MOBILITY, ESPECIALLY IF TASK INVOLVES MATERIAL HANDLING OR DIFFICULT ACCESS
- TASK REQUIRES DIRECT COMPUTER INPUT

- TASK REQUIRES IMMEDIATE FEEDBACK OR USE OF RESULTS FROM DATA INPUT

Utilization of a list of criteria such as that above enables a decision maker to classify a task as a viable candidate or not a candidate for enhancement by VDE. Such a list does not provide a mechanism for categorizing a large set of tasks in a operation in a manner that would enable the tasks to be ranked according to their degree of compatibility with VDE procedures.

A major activity of the VDE component of this project has been the development of a scheme that would enable a VDE compatibility index to be readily determined for the orbiter processing tasks performed at the Kennedy Space Center. The availability of this index value for each task will readily enable decisions about which activities could be enhanced by VDE, which activities are marginal candidates for VDE application, and which are unlikely candidates. Within each of these categories the index values could be used to establish a "ranking" of the tasks.

## 5.2 EVALUATION SCHEME FORMAT AND MACRO CRITERIA

The approach developed by the Industrial Engineering Department at UCF is a variation of the widespread matrix evaluation procedure developed by the Oregon Productivity and Technology Center of the Oregon State University (Safford, 1986). Matrix evaluation schemes have been widely used over a long period of time in the multi factor evaluation of alternatives in industrial processing situations (Reed, 1961).

Three macro criteria are suggested for initial use in the matrix procedure to enable arriving at a measure of a data entry tasks compatibility with VDE:

1. BENEFITS: Improvements to NASA's mission and Shuttle System operation expected from improvements in the information obtained from the data system. Consideration of "benefits" will limit itself to beneficial factors not normally measured in dollars (e.g. improved scheduling, task time reduction, etc.).
2. FEASIBILITY: The ease with which VDE can be incorporated into a task.
3. COST: The increase or decrease in dollar costs associated with incorporation of VDE into a data entry task.

These macro criteria could of course be considered simultaneously when evaluating a candidate data entry tasks compatibility with VDE. It is suggested, however, that each of these macro criteria be considered separately for all candidate data entry tasks. "Scores" on each macro criteria can then be systematically combined to allow an overall measure or index of compatibility to be derived.

The evaluation procedure calls for a task being considered to be assigned a score from 0-10 on each of the macro-criteria. Score sheets, described below, systematically guide the decision maker in this scoring process. After the task is scored on each of the macro-criteria a weight is assigned to each of the criteria. These weights totaling 100% are

determined by consensus from a group of "experts." The weights are then multiplied by the respective scores and the products are summed to furnish the "VDE compatibility index." The results of the aforementioned review and computation procedure would be summarized in the "VDE compatibility index matrix" form shown in figure 4.

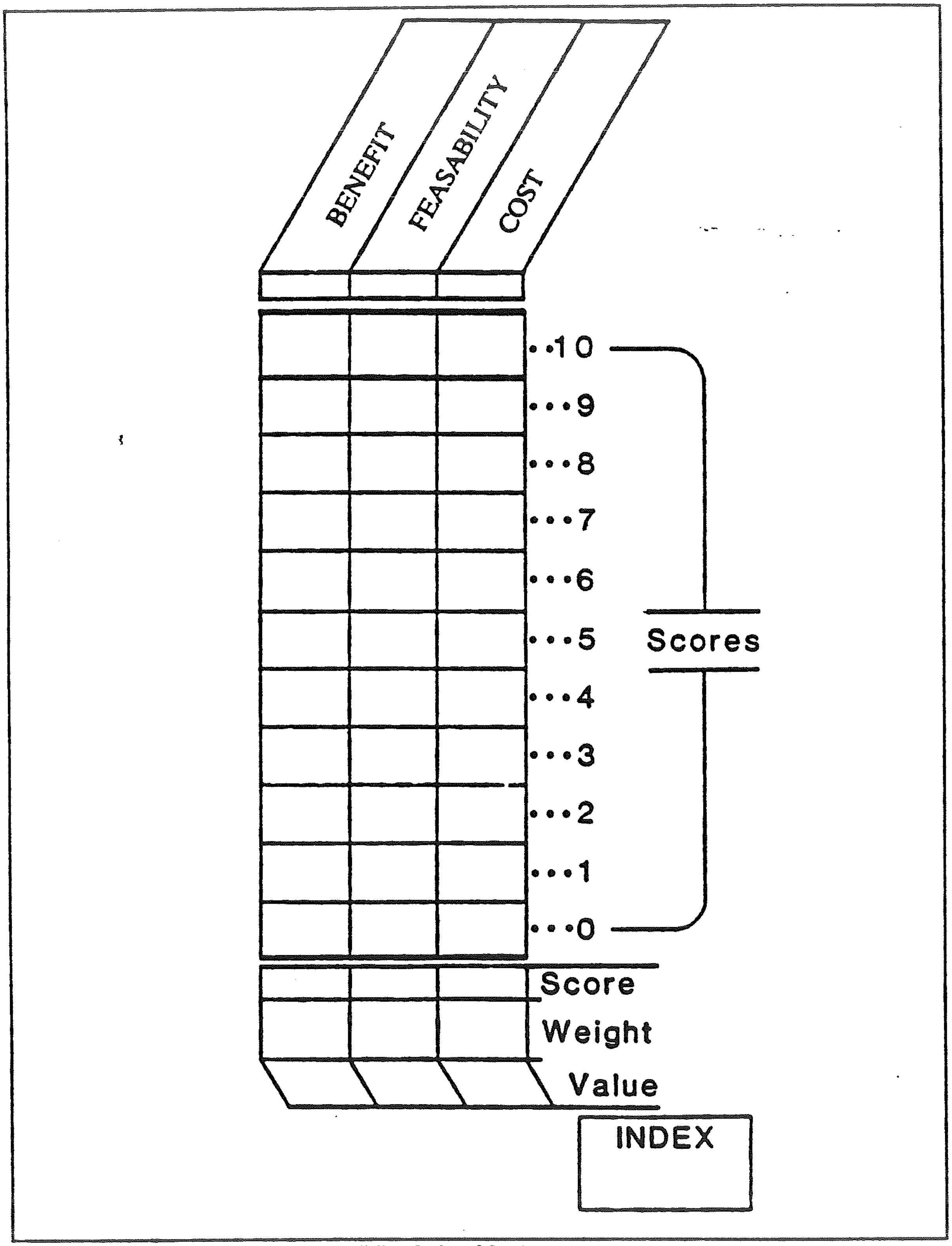


**Figure 4** -- Voice Data Entry Compatibility Index Matrix.

## 5.3 DETERMINATION OF A "BENEFITS" SCORE

In order to utilize the matrix approach for delineating a VDE compatibility index for an orbiter processing task it will first be necessary for the evaluation team, the composition of which is described later in the report to assign a score from a scale of 0 to 10 to the benefits likely to be achieved by enhancing the task with VDE.

To enable this assignment of a score to be done in a systematic and consistent fashion it is suggested that the evaluation team consider the factors identified in table 5. These factors are expressed in the form of nine questions concerning the likelihood of experiencing potential benefits from VDE implementation.

| TABLE 5 -- FACTORS TO BE CONSIDERED IN DETERMINING BENEFITS SCORE | | |
|---|---|---|
| A. | TASK PERFORMANCE BENEFIT FACTORS | |
| | 1) | Would the task performance be improved by VDE enabling more "free" use of hands |
| | 2) | Would the task performance be improved by VDE enabling less eye movement away from task |
| | 3) | Would the task performance be improved by audible feedback to operator |
| | 4) | Would task performance time be reduced |
| B. | TASK QUALITY IMPROVEMENT BENEFIT FACTORS | |
| | 1) | Would data entry errors be reduced due to VDE real time error checking |
| | 2) | Would VDE result in reduction of transcription errors |
| | 3) | Would "precision" of information obtained by operator be improved due to VDE |
| C. | OTHER BENEFITS ASSOCIATED WITH VDE AND COMPUTERIZATION | |
| | 1) | Would VDE and its associated computerization better define task procedures for the operator |
| | 2) | Would data be more instantly accessible and useful to other orbiter processing users |
| | 3) | Would the direct computer access enabled by VDE be beneficial |

If none of the potential benefits are likely to be achieved then a score of 0 would be appropriate. If all nine of the benefits are likely then a score of 9 would be appropriate. Six of the potential benefits would warrant a score of six. Adjustments to the initial score derived from tallying benefits would be made in the following manner. If a benefit would

not be possible in the process as it is currently structured by might be realized with minor modifications to the process fractions of a point (e.g. ½) could be assigned in the score. Adjustments could be make for unusually large significant benefit improvements by assigning more than a single point to a benefit. Similarly, disbenefits, loss of a current benefit, resulting from VDE implementation would be reflected by subtraction of points from the base score of benefits. Potential benefits not listed in the table would also be recognized with points. Adjustments to the base score would be noted by the observation team on a comments sheet and the reasons for the adjustments would be briefly explained.

After systematically considering the benefits in the aforementioned manner the evaluation team would round their score to the nearest integer on the range 0 to 10 and mark the score sheet of the task accordingly.

## 5.4 DETERMINATION OF A FEASIBILITY SCORE

The feasibility or ease of incorporating VDE technology into an existing orbiter processing task would be assigned an integer value in the range of 0 to 10 in the following manner which is similar to that employed in the assignation of the benefits score.

The evaluation team would first consider the feasibility factors presented in table 6. A base score of 1 times the number of factors present with respect to the task being considered would initially be assigned. For example, if five of the factors listed are present an initial score of 5 would be assigned. Additional factors contributing to feasibility identified by the team, or for potential applicability of factors given minor process modifications, would be considered in the same manner as described in the determination of a benefits score.

| TABLE 6 -- FACTORS TO BE CONSIDERED IN DETERMINING FEASIBILITY SCORE | |
|---|---|
| 1) | Is the task already computerized and the task process already one of data entry |
| 2) | Does well defined vocabulary exist for the information collected in the task |
| 3) | Is the vocabulary limited to a size that can be readily handled by available VDE equipment |
| 4) | Is a structured vocabulary sequence in place for the information to be obtained |
| 5) | Is there a limited "speaker" population |
| 6) | Is the speaker population stable |
| 7) | Is the speaker population composed of persons with "similar" speech patterns |
| 8) | Is there readily available physical access to the computer |

As with the benefit score, the feasibility score developed by the team would be rounded to the nearest integer in the range 0 to 10 and an appropriate mark for the score would be made on the score sheet.

## 5.5 DETERMINATION OF A COST SCORE

An integer score in the range of 0 to 10 would be determined by the evaluation team in a manner similar to that described for the benefit score and the feasibility score. The cost factors shown in table 7 will be used in the scoring procedure by the evaluation team.

TABLE 7 -- FACTORS TO BE CONSIDERED IN DETERMINING COST SCORE

| | |
|---|---|
| A. | EQUIPMENT COSTS<br>1) Higher than ordinary VDE equipment costs<br>2) Higher than ordinary additional hardware or equipment costs (including additional computer equipment required by VDE)<br>3) Additional requirements for remote transmission, portability, or special computer linkages |
| B. | PROGRAMMING COSTS<br>1) Extensive programming requirements for application program module<br>2) Extensive programming to handle highly variable message structure |
| C. | TRAINING COSTS<br>1) Operator training costs<br>2) "Computer" training costs |
| D. | PROCESS DEFINITION COSTS<br>1) Task restructuring to enable VDE<br>2) Vocabulary and structure formulation and development |

## 5.6 EXAMPLE APPLICATION

A generic example will serve to illustrate the manner in which the observations and computations associated with the determination of the VDE compatibility index are summarized in a matrix form. A data collection activity associated with orbiter processing is examined by the review team and scores of 8, 6, and 3 are recorded respectively for the benefit, feasibility, and cost criteria. The team using a nominal group technique approach determines that weights of 45, 40, and 15 are the appropriate ones to assign to the three criteria. These values are entered in the matrix shown in figure 5. Appropriate products of weights and scores are formed and are added together to form an index in the range 0 to 1000.

More specifically in this example, the "benefit" score of 8 is multiplied by its weight of 45 to produce a product of 360. Similar procedures for the "feasibility" and "cost" columns produce products of 240 and 45 respectively. The sums of the products for the criteria produce an overall "VDE compatibility index" of 645 for this task.

The availability of this index will assist the decision maker in determining the viability of the task for actual VDE and will be useful in "ranking" this task with respect to others being considered for VDE.

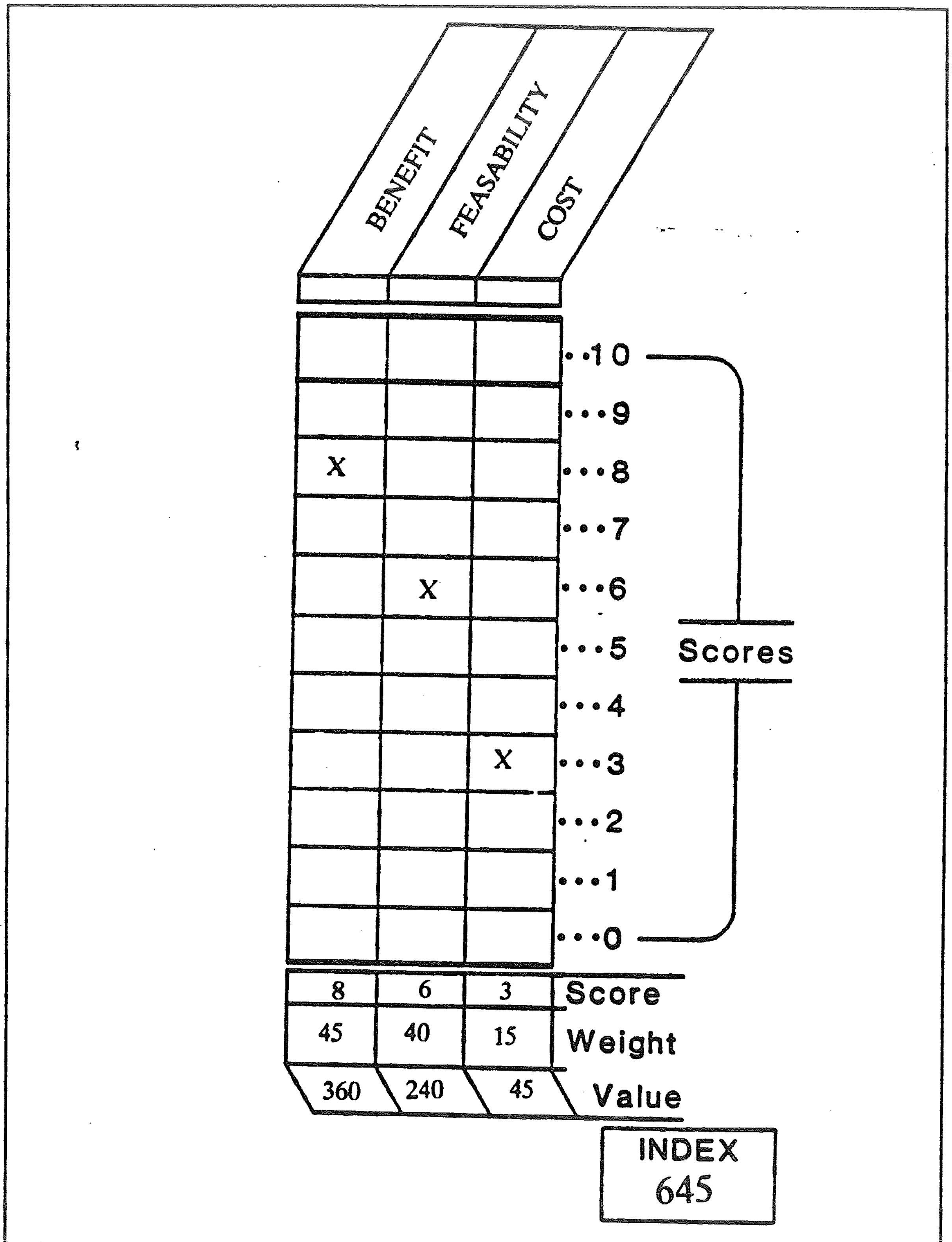


Figure 8 -- Generic example of a VDE compatibility index matrix calculation.

## 5.7 SUMMARY AND SUGGESTIONS FOR IMPLEMENTATION

The evaluation methodology developed in the current period of the VDE component in this project should provide a useful means for determining VDE compatibility index for orbiter processing tasks. As indicated in this report, the use of this evaluation procedure would best be undertaken by a team of individuals knowledgeable about the evaluation procedures and the orbiter processing tasks. It is suggested that the team be composed of at least three members. Possible composition of the team would include:

- A KSC representative familiar with orbiter processing procedures
- A Lockheed representative familiar with the orbiter processing procedures
- A University of Central Florida, or other representative familiar with the evaluation procedure and orbiter processing activities

The aforementioned team would be responsible for scoring each task with respect to VDE benefits, feasibility, and cost. The team would also be responsible for assigning weights to each of these three macro-criteria for each task that is evaluated.

The evaluation team would also have some responsibility for refining the process after a period of on-site trial usage. Such a trial would involve consideration and definition of additional macro-criteria to the matrix and refinement, revision, or addition to the tables of factors to be considered in scoring each criteria.

As mentioned previously, the availability of a systematically derived numerical VDE compatibility index should assist the decision makers responsible for determining VDE applications. The index values and procedures do not of course replace sound managerial judgement but are designed to aid the process requiring consideration of a number of quantifiable or semi-quantifiable factors.

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# Appendix III

# Cavity Digitization Report

# Appendix III.1 Cavity Digitization Interim Report

# Cavity Digitization

# Technical Feasibility Study

# Interim Report

November 1990

**Cavity Digitization at KSC**
**Technical Feasibility Study**

**Interim Report**

## INTRODUCTION:

The objective of this study is to determine the technical feasibility of building a device which through the use of laser or optical based technology and geometric arrangement will collect 3-D descriptive information of a tile cavity in the orbiter. The information can be analyzed and translated into a machining program to cut/mill a replacement tile to fill the cavity.

This document summarizes the findings of the study and recommends a course of action for KSC and UCF.

## SYSTEM ELEMENTS:

- Digitization Apparatus
- CAD/CAM
- NC milling machine

Regardless of the Digitization apparatus, elements 2. and 3. are the same, and can be acquired/ developed separately. The outcome of the digitization can be in the form of a data file which can be graphically displayed and/or supplied directly to a CAD/CAM system.

Digitization Apparatus:

A large number of devices was surveyed and studied for the digitization application at KSC. The devices based on laser triangulation were the most promising. Two methods/systems are described here which differ on their technology, arrangement of their components, digitization density (expected accuracy) and the set-up.

1. High Speed Laser Scanning (System One):

An integrated System composed of:

- Non contact laser scanner
- System controller
- Graphics Display
- Coordinate Measuring Machine or an X,Y movement mechanism

Through a synchronized scanning design, a single point laser beam is projected onto the surface of the orbiter (the cavity and its surrounding tiles). A diffuse reflection is collected back by the system and imaged onto a linear photodiode array. The position of the Gaussian peak of the scattered beam on the array provides the Z coordinates for the surface. An oscillating mirror is used to deflect the laser spot along the surface on one axis. The mirror position provides the X coordinate. The position of the scanning head is used to determine the Y coordinate for each point scanned. A CMM may provide the known Y movement. In the cavity application where digitization has to be performed overhead, a mechanism has to be devised to provide and measure the Y position.

The developer of this technology is the National Research Council of Canada (NRCC) and has given licenses for system developments to two Canadian companies (HYMARC LTD of Ottawa, Ontario and SERVO-ROBOT of Montreal, Quebec).

The technology provides for a turn-key system to be designed and to mount on a Coordinate Measuring Machine (CMM) and/or a robot arm to scan an object in a fixed position. Scanning is non-contact and will vary in the width depending on the required accuracy. Data can be collected in a step and repeat mode or continuous mode. Data collection rate is 10,000 points per second. The system may feature a real time graphics display, automatic view integration, data storage, data transfer through an Ethernet port and data formatting.

A sample cavity was digitized using the Hyscan 3-D laser Digitizer of Hymarc. The experiment produced promising results. The attached figure shows an isometric view of the cavity extracted from the generated data points. The System cost is $100,000 without the CMM.

Using such system for the cavity digitization will require developing a mounting mechanism which can be either in contact with the orbiter or used as stand alone (non contact).

This system described above will be identified as "System One" in the system evaluation section.

2. Image Processing-Based Digitization (System Two):

In this technique, the previous knowledge that the cavity is composed of planars is used. A digitizer using an image of displayed fringes, a frame grabber, and image processing software, sufficient points are digitized to produce the cavity surfaces. Through software the interactions of these surfaces are used to generate edges representing the boundaries of the cavity.

There was no system in existence that could be evaluated experimentally. Lockheed Missile and Space (LMSC) of Palo-Alto, California uses a similar technique in one of their current projects. For this reason it is assumed that LMSC is capable of building a system with these features.

This system will be refereed to as "System Two" in the system evaluation section.

**APPLICATION CRITERIA AND SYSTEM EVALUATION:**

1. Static Accuracy: Measurement error inherent to the digitizer.

    System One:
    Claimed accuracy by the developers are within the required accuracy of 0.005". Sample test verifies the claim. High density scanning enables capturing surface curvature. Processing and displaying surface feature is on-line.

    System Two:
    Based on the Step and Gap device, accuracy is within range assuming cavity is made up of plane surfaces. Curved surfaces can not be measured. Image Processing is done off-line.

2. Dynamic Accuracy: Measurement error due to changes between cavity and digitizer coordinates during digitization.

    System One/ Two:
    Although there was no quantification of the orbiter oscillation, the speed of the laser scanning / digitizing should reduce the dynamic error. In either of the two systems it is recommended that a stable positioning system be developed for digitization. A contact system to the orbiter is recommended whenever possible to enable stability.

3. Physical Requirements: Digitizer and positioner weight, standoff, reflectivity,compactness and their effect on efficient digitization.

    System One:
    Requires building a replacement for the CMM used in the laboratory demonstrations. An x,y,z mechanism capable of moving the scanning head in one direction (linear movement) will be required. The mechanism movements should be coordinated with the scanning procedure (equivalent to an inverted CMM). The software supplied with the system is capable of integrating multiple scans. Weight of the scanning head is manageable.

System Two:
Requires building a mechanism similar to the step and gap, however much larger to accommodate the entire cavity and to provide for enough projectors to avoid the shadow effect. A structure is required to house the system elements with fixed angles. Calibration may be required before use.

4. Ease of Use:

System One/Two:
Both systems will require user participation in the design to assure its acceptability by the technicians. Beyond the standard user friendly software methods, human factors considerations and rules for human- machine interface have to be considered in each of the development stages.

5. System Reliability:

System One:
System components are off-the-shelve and the system has been in use for a number of years in other applications. The fact that there was a digitization experiment which resulted in a CAD output through scanning proves a relatively reliable integrated system. An overall reliability for the space shuttle cavity application cannot be estimated at this stage.

System Two:
System component has to be integrated and a system has to be built. No system was tested.

6. Cost:
System One:
Rough estimate of $200,000. This will include the development of the mounting mechanism.

System Two:
Not available.

CONCLUSIONS:

1. Cavity digitization and producing a replacement tile is technically feasible using the laser triangulation technique and CAD/CAM technology.

2. Laser scanning is more accurate than sample digitization and the speed of digitization should offset the effect of orbiter oscillation/ vibration (reason sighted for other system failures).

3. Off the shelf laser scanning equipment exists, however special mechanisms must be built for the cavity application.

4. Extensive experimentation is required, on simulated test-bed using tile technicians, before commissioning the system.

**RECOMMENDED COURSE OF ACTION:**

1. KSC should initiate a design and development phase for cavity digitization system using the laser scanning or image processing based technology. The NRCC technology is recommended at this stage.

2. The University of Central Florida (UCF) and Lockheed Space Operation Co. (LSOC) would cooperate in the system development.

3. UCF, LSOC and NASA personnel would cooperate in software modification and on site experimentation.

**JUSTIFICATION:**

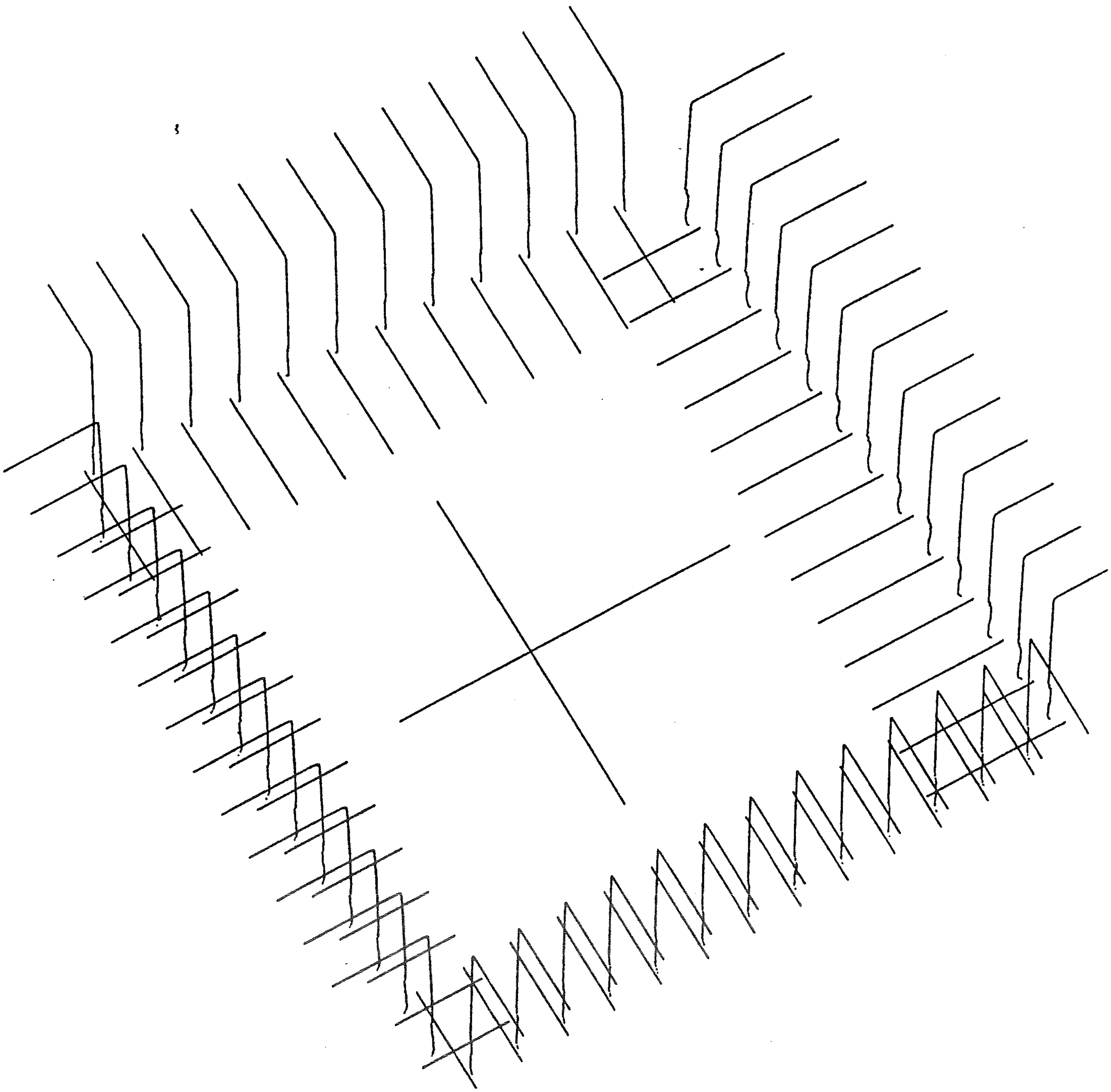
- Both UCF, LSOC, and NASA researchers are more familiar with the technology and the problems associated with its application at KSC than other potential developers.

- UCF had acquired seed funds from FHTIC for researching the problem and had developed an initial feasibility study.

- UCF maintains a laboratory testbed for any experimentation of the system.

- UCF maintains a library for equipment, specifications, studies,..etc. which should be of great value in the development phase.

- UCF is in the process of acquiring a CMM and a set of laser measuring equipment to be used for calibration and experimentation.



Lockheed Space Operations Company
1100 Lockheed Way
Titusville, Florida 32780

November 26, 1990
KKW.9043HOSNI

Dr. Yasser Hosni
Industrial Engineering Department
College of Engineering
University of Central Florida
P. O. Box 25000
Orlando, Florida 32816

Dear Dr. Hosni:

I had reviewed your summary report to NASA and the project plan setup by your group at UCF and our group here at LSOC regarding the Cavity Digitization project. By this letter I am informing you that we are fully committed to the project over the span of its duration according to the plan. We have budgeted the amount of $125,000 for the project during its first year, and we expect a similar amount in the second year. It is our understanding that UCF will participate in this project supported by the "Photomechanics in the Manufacturing and Repair of Space Shuttle Tile Protection System" study currently funded by Florida High Technology and Industry Council (FHTIC) and the productivity study supported by NASA/KSC.

We congratulate the team project on the conclusion of the feasibility phase, and we are looking forward to a successful development phase.

Sincerely,

Ken Wagy

K. K. Wagy,
Director

cc: Mr. Tom Davis (PT-AST)
Mr. Tim Barth (TV-PEO-12)
Dr. Ed Hecker (TM-PCO-2)
Dr. S. Rice (UCF/COE)

# Appendix III.2 UCF/LOSC Project Plan

# LSOC/UCF
# CAVITY DIGITIZATION

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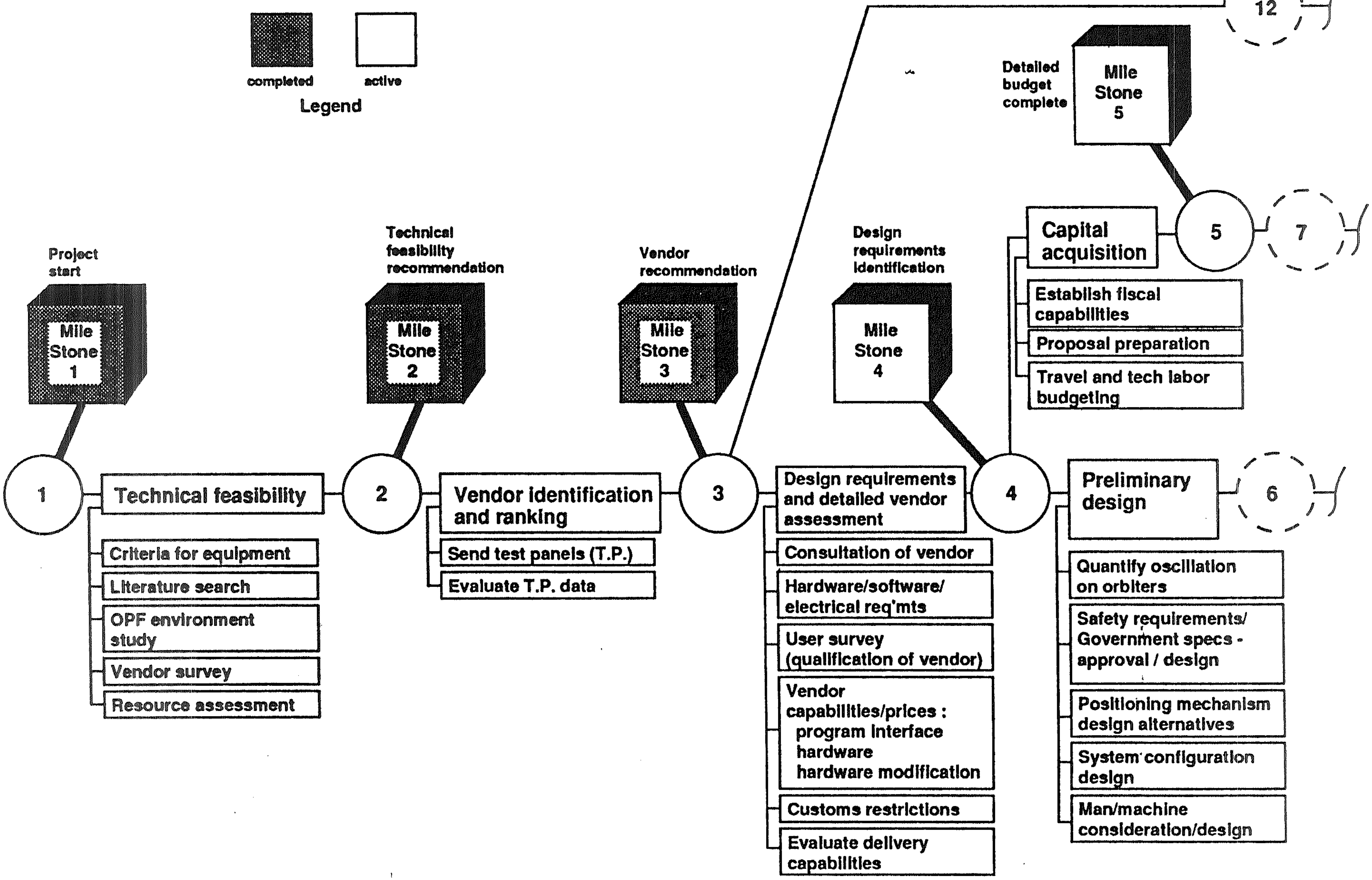
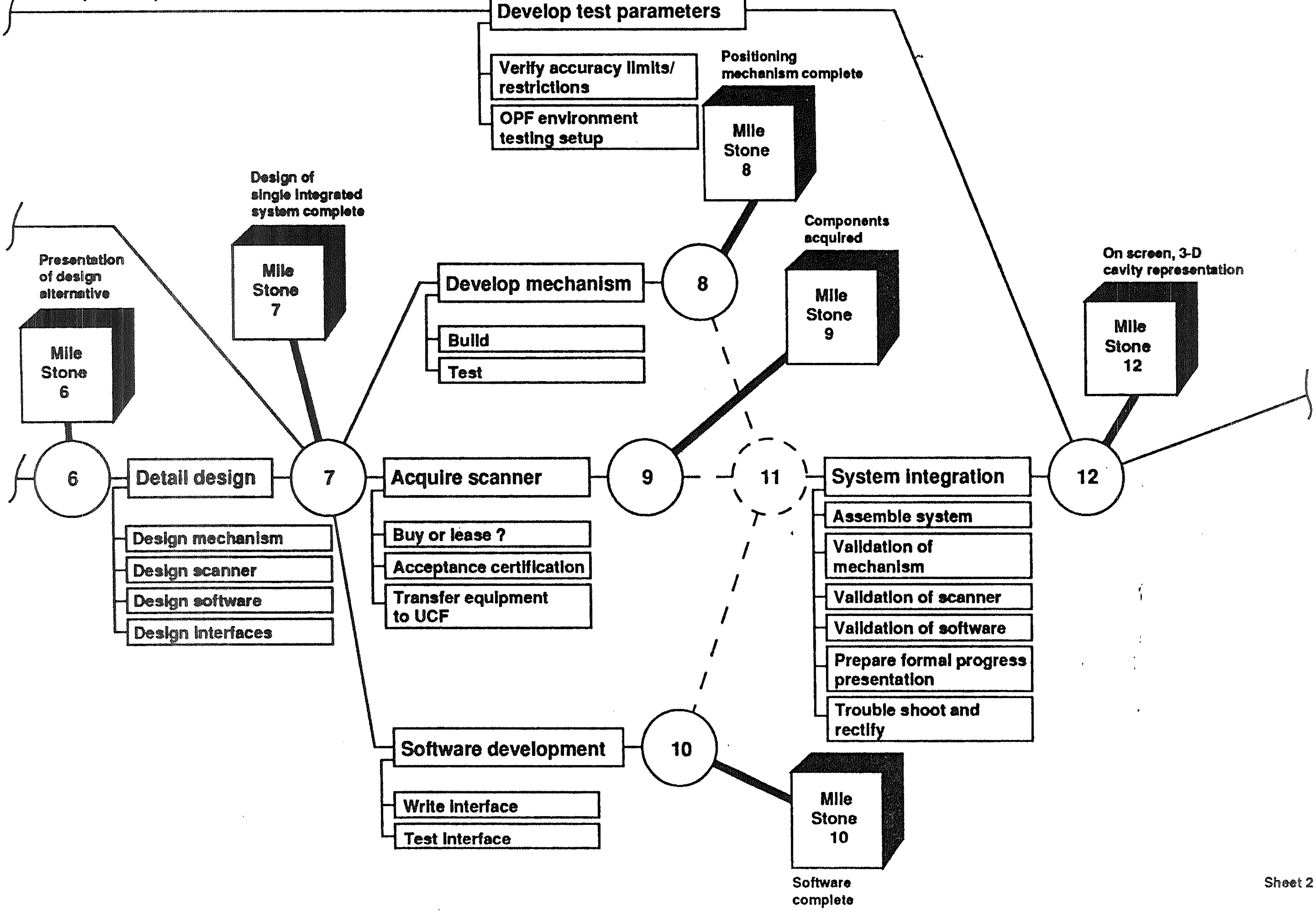


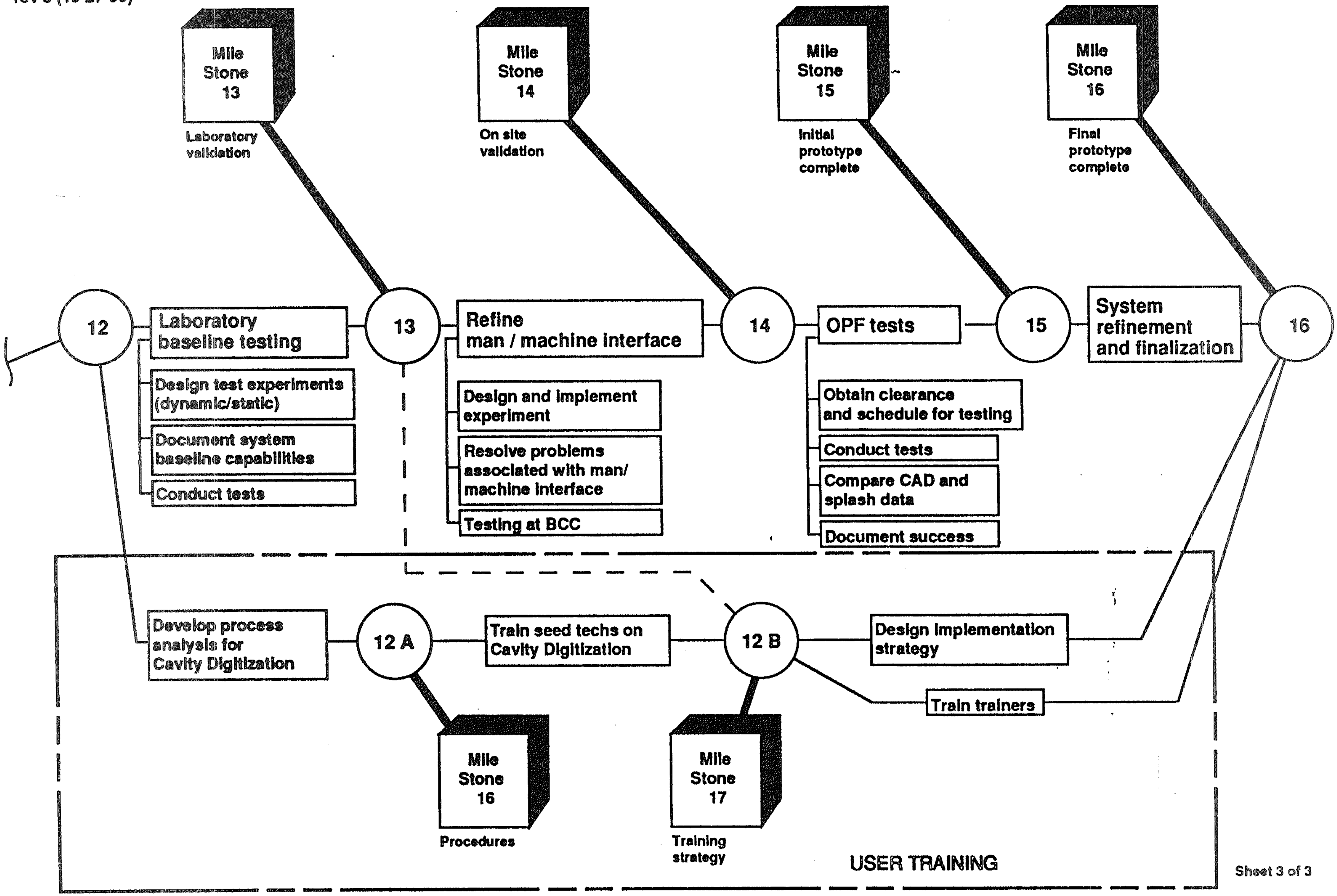
# LSOC/UCF
# CAVITY DIGITIZATION

rev 5 (10-27-90)



# LSOC/UCF
# CAVITY DIGITIZATION

rev 5 (10-27-90)



Following is the description, duration and tasks associated with each activity. The layout of the description is as follows :

1. Activity name.
2. Nodes (i,j).
3. Duration.
4. Outcome (milestone).
5. Tasks, steps and procedures.
6. Responsibility.

## I. ACTIVITY : TECHNICAL FEASIBILITY

NODES : (1,2)

DURATION : 12 weeks

OUTCOME :

Technical report detailing techniques, vendors, criteria for evaluation, literature search, similar experiences and recommendations.

TASKS, STEPS AND PROCEDURE :

- Study literature & previous experience.
- Conduct initial vendor survey and identify equipment.
- Study problems associated with on site application (OPF environment).
- Assess Resources available.

RESPONSIBILITY :

- UCF

## II. ACTIVITY : VENDOR IDENTIFICATION AND RANKING

NODES : (2,3)

DURATION : 12 weeks

OUTCOME :

Vendor recommendation, identify all possible vendors by technique and ranking with respect to performance.

TASKS, STEPS AND PROCEDURE :

- Detailed assessment of vendors.
- Test panel preparation and send out for testing and verification.
- Assess results with respect to performance, ease, feasibility, constraints and limitations.
- Visits with selected vendors.

RESPONSIBILITY :

- UCF

## III. ACTIVITY : DESIGN REQUIREMENTS AND DETAILED VENDOR ASSESSMENT

NODES : (3,4)

DURATION : 4 weeks

OUTCOME :

Design requirements and functions of system elements compatible with the highest ranking vendor equipment.

TASKS, STEPS AND PROCEDURE :

- Consultations with highest ranked vendor.
  (visits, telephonic conversations, correspondence, etc.)
- Conduct user survey and assess.
- Identify Hardware/Software/electronic requirements.
- Obtain prices, Costs, and Capabilities.
- List and resolve problem associated with imports if applicable.
- Evaluate delivery schedule capabilities.

RESPONSIBILITY :

- UCF/LSOC

## IV. ACTIVITY : PRELIMINARY (CONCEPTUAL) DESIGN

NODE : (4,6)

DURATION : 8 weeks

OUTCOME :

Set of alternative design approaches. The Current trends are:

1. Hand held device, with contact or non-contact to the orbiter.
2. Stand alone device - contact of non-contact - which may be completely integrated on a special stand.

TASKS, STEPS AND PROCEDURE :

- Brainstorming sessions between LSOC, UCF, NASA, and the vendor.
- Experiment on the orbiter with the intent of obtaining quantifiable data to the orbiter oscillation/vibration.
- Set limits on design compatible with government specifications and obtain approvals (the use of laser, contacts to orbiter, schedule, etc.).
- Set limits on system performance (accuracy, device use by technicians, etc.).
- Produce a number of design approaches compatible with design specifications.

RESPONSIBILITY :

- UCF/LSOC

V. ACTIVITY : CAPITAL ACQUISITION

NODES : (4,5-7)

DURATION : 6 weeks(continuous)

OUTCOME : Secure the necessary funds and budget for the project

TASKS, STEPS AND PROCEDURE :

- Approach interested parties (LSOC, UCF).
- Prepare and submit proposals (FHTIC, NASA,others).
- Follow-up with proposals.

RESPONSIBILITY :

- UCF/LSOC

## VI. ACTIVITY : DETAILED DESIGN

NODES : (6,7)

DURATION : 8 weeks

OUTCOME :

One single design will be selected, elements breakdown of the system. Elements classified as: purchased or developed. For those developed elements, detailed drawings will be produced. Software to be developed is identified by function, and its interface with other acquired/CAD software used in tile manufacturing. Final integrated assembly drawings.

TASKS, STEPS AND PROCEDURE :

- Evaluation of each of design approaches will take place through consultations between equipment vendor, LSOC, UCF, and NASA using limits of design and system performance identified in (4,6).
- The Optimal design will be selected and approved by all concerned parties. (optimality will be with respect to performance, productivity, practicality, man/machine interface, feasibility and cost).
- Identify standard elements which may be acquired as ready made.
- It is expected that the main elements of the system will be:
  - Mechanism for scanner movement and its control.
  - Scanner and its controls.
  - Software for system elements integration and control.

Interface between system and other complementary systems (CAD/CAM & technicians).

- For hardware elements to be developed by LSOC and/or UCF, detailed specifications, drawings, etc. will be produced by part, and assembly. For software elements to be developed by LSOC and/or UCF detailed specification of program function and data (input and the expected output) will be produced.
- For elements to be acquired through buying and/or leasing complete specifications and vendor identification will be produced. It is expected that the scanner vendor will be the major element subcontractor, however others may be involved.

Based on the macro identification, the system elements are:

1. Mechanism
2. Scanner
3. Software

P.S. This activity can be considered as a baseline for configuration management.

<u>RESPONSIBILITY</u> :

- UCF/LSOC

Three activities are identified per the network associated with the development phase.

(7,8,11) Development of the mechanism.

(7,9,11) Acquisition of the scanner as the major component for outside acquisition.

(7,10,11) Development of Software.

These development activities for system elements once completed, will be followed by a System integration activity (11,12).

Following are the details of each of these development activities (7,8-11), (7,9-11), (7,10-11) & (11,12).

## VII. ACTIVITY : DEVELOPMENT OF THE MECHANISM

NODES : (7,8-11)

DURATION : 8 weeks

OUTCOME :

Complete positioning mechanism. Such mechanism may include all the necessary hardware in reliable material, motors, and measuring system. Depending on the design, the mechanism may receive its instructions for positioning the scanner holder through computer program, or would have the capability of identifying its relative position once it moves (either mechanically or automatically).

TASKS, STEPS AND PROCEDURES :

- Translation of the detailed design into an assembled mechanism. This will require the acquisition of material, machining of the parts, as well as assembling. It is expected that more than one mechanism will be built (possibly 3) at the same time. Depending on the design approach, it is possible to use a robot-type mechanism to avoid the development of new software. For such case, a gripper would have to be manufactured to fit the scanner.
- The mechanism will then be tested using local test data.

RESPONSIBILITY :

- LSOC

VIII. ACTIVITY : ACQUIRE SCANNER

NODES : (7,9-11)

DURATION : 6 weeks

OUTCOME :

Scanner compatible with the detailed design will be acquired. Depending on the cost, the capital committed and the expenditure, the scanner can be acquired through purchasing or leasing it for the duration of the project.

TASKS, STEPS AND PROCEDURE :

- Consultation with the vendors and negotiating prices, capabilities, delivery schedule, shipment schedule, tentative ownership agreement, etc.
- Transfer of the contracted components to the UCF laboratories where initial experimentation will take place.
- Experimentation, functional testing, and acceptance of the scanner using standard test beds, and familiarization with the equipment.

RESPONSIBILITY :

- UCF

## IX. ACTIVITY : SOFTWARE DEVELOPMENT

NODES : (7,10-11)

DURATION : 8 weeks

OUTCOME :

Complete software package made up of a number of programs to accomplish design functions. Expected functions are in controlling the scanning head, integration of scanning pictures, data base development, CAD representation, and user interface.

TASKS, STEPS AND PROCEDURE :

- For each program:

  (a) Logic design : data flow and/or representation on the screen, and developing test data,

  (b) Coding of the programs making the maximum use of standard packages.

  (c) Testing the programs individually as well as in integration with other programs.

- Consultation with component/scanner developer to acquire the necessary design parameters during all stages of program development.

- Consultation with technicians/users for the most efficient way of user communication and man-machine interface.

- Consultation with the next phase of cavity replacement, i.e. the milling of the tile, to design an output format compatible for tile manufacturing.

<u>RESPONSIBILITY</u> :

- LSOC

## X. ACTIVITY : SYSTEM INTEGRATION

NODES : (11,12)

DURATION : 5 weeks

OUTCOME :

Completed integrated system (mechanism, scanner, software, user).

TASKS, STEPS AND PROCEDURE :

- Assembly of the mechanism, the scanner, and the software to form the cavity digitization system. This activity will also involve "acceptance" level bench testing of the system to insure its readiness for subsequent activities. The milestone associated with the completion of this activity will be the capability of displaying a three dimension representation of test tile cavity on a computer screen.
- Test the individual cavity digitization components (i.e. mechanism, scanner, software).
- Test the ability of the system to function as a whole.
- Rectification of any system problems, on the system, as well as component level.
- Use system to scan a test tile cavity and display the results on a display terminal screen.
- Prepare a formal presentation of progress to date.

RESPONSIBILITY :

- UCF/LSOC

## XI. ACTIVITY : DEVELOP TEST PARAMETERS

NODES : (3,12)

DURATION : 5 weeks

OUTCOME :

- Identify system output parameters necessary for CAD

- Fabricate test panels complete with all critical parameters, measured to the required accuracy.

TASKS, STEPS AND PROCEDURE :

- Study the critical parameter with CAD shop.
- Build a test panel (a worst case) and measure it to the highest accuracy (include an oscillating stand) using data collected from actual orbiter oscillation.
- Document the findings as a standard for comparison.

RESPONSIBILITY :

- UCF

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probability (or level of confidence). Experiments will be conducted in the laboratory facilities at UCF.

- Perform the necessary analysis dictated by the statistical experimental design. A detailed description of system baseline capabilities and the reference conditions of the baseline capabilities test will be prepared.
- Operational analysis, time measurement, and expected gain in productivity.

<u>RESPONSIBILITY</u> :

- UCF

XIII. ACTIVITY : REFINE MAN-MACHINE INTERFACE

NODES : (13,14)

DURATION : 15 weeks

OUTCOME :

Laboratory prototype of the cavity digitization system complete, compatible and acceptable by the technicians who will use it, (user friendly)

TASKS, STEPS AND PROCEDURE :

- Carry on a work analysis procedure for actual technicians using the system.
- Identify and rectify any problems associated with the use of the prototype (man-machine interface). Such rectification may involve redesigning of procedure, hardware, and/or software. May require conducting the study at BCC-Space Technology Institute.

RESPONSIBILITY :

- UCF

XIV. <u>ACTIVITY</u> : <u>OPF ON-SITE TESTING</u>

<u>NODES</u> : (14,15)

<u>DURATION</u> : 17 weeks

<u>OUTCOME</u> :

Completion of these activities will yield an indication of on-site baseline system capabilities and will complete the initial prototype development.

<u>TASKS, STEPS AND PROCEDURE</u>:

- Schedule testing at the target facility.
- Obtain necessary approval.
- Conduct test.
- Compare CAD output to splash process.
- Document "lessons learned" with respect to environment, technician's acceptability, equipment performance.
- Expected number of cavity testing will be determined based on the experiment design.
- Possible application test may extend to VAB and the launch pad.

<u>RESPONSIBILITY</u> :

- LSOC

## XV. ACTIVITY : USER TRAINING

NODES : (12,16)

DURATION : 12 weeks

OUTCOME :

- Training enough trainers and technicians (expected 5)
- A training strategy and implementation strategy
- advise for certification process.

TASKS, STEPS AND PROCEDURES :

- Develop procedure for the new device.
- Develop training strategy and train seed trainers
- Develop an implementation strategy
- Training trainers at LOSC
- Supervision of training sessions for technicians by trainers.
- Rectify and document strategies.

RESPONSIBILITY :

- UCF

## XVI. ACTIVITY : SYSTEM REFINEMENT AND FINALIZATION

NODES : (15,16)

DURATION : 4 weeks

OUTCOME :

Final approved prototype with complete supporting documentation and guideline for commercialization.

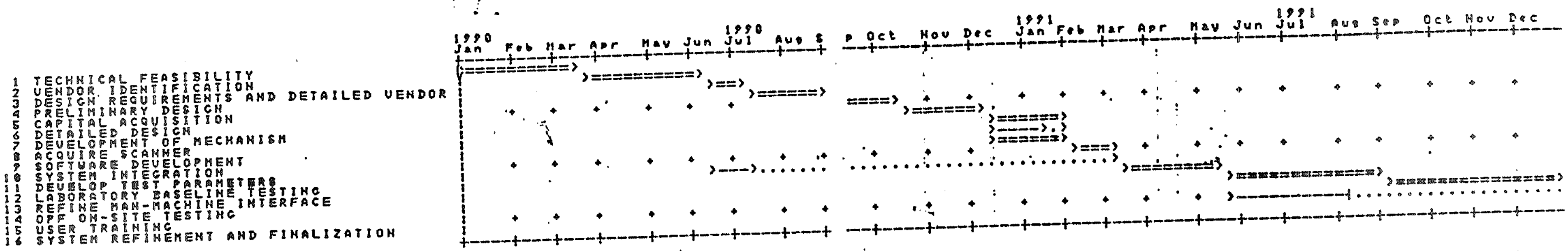
TASKS, STEPS AND PROCEDURE :

- Tasks associated with this activity will enable the final prototype of the cavity digitization system to be completed and will specify the cavity measurements and evaluation procedures necessary for implementation into the standard OMI's.

RESPONSIBILITY :

- UCF/LSOC

The details i.e. time, activity name, % completed have been used in creating the schedule. The schedule of this project has been arrived at by using Microsoft Project. The print out of the schedule is attached.


1 TECHNICAL FEASIBILITY
2 VENDOR IDENTIFICATION
3 DESIGN REQUIREMENTS AND DETAILED VENDOR
4 PRELIMINARY DESIGN
5 CAPITAL ACQUISITION
6 DETAILED DESIGN
7 DEVELOPMENT OF MECHANISM
8 ACQUIRE SCANNER
9 SOFTWARE DEVELOPMENT
10 SYSTEM INTEGRATION
11 DEVELOP TEST PARAMETERS
12 LABORATORY BASELINE TESTING
13 REFINE MAN-MACHINE INTERFACE
14 OPPF ON-SITE TESTING
15 USER TRAINING
16 SYSTEM REFINEMENT AND FINALIZATION
1990
Jan Feb Mar Apr May Jun Jul Aug S p Oct Nov Dec
1991
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

Appendix III.3 Tally of experiments for laser equipment at UCF.

August 30, 1990

Experiment abstracts

Background: The following experiments are suggested to acquaint the members of the KSC project, cavity digitization group with the workings and capabilities of a Candid Logic Precimeter Probe.

The purpose of these experiments in the first stage is to validate the capabilities of the probe for quantifying object with 3-D information feedback. All these sub-experiments are the preliminary tests for simplifying the 3-D situation into 1-D situation. The further experiments are going to be set up based on the results in the first stage. The present experiments are intended to accomplish the following:

1. Demonstrate the abilities of the probe. To include verifying the manufactures claim to repeatability, accuracy and operating limits.

2. Establish requirements for a motion control system for laboratory manipulation of the probe.

3. Familiarize personnel with the probe, probe controller, motion controller, and the use of a personal computer to control both the probe and motion control system.

4. Demonstrate the feasibility of digitizing a cavity with the probe, and the feasibility of quantifying vibration with the probe.

5. Establish the effects of orientation between the probe and the target. Also, consider the effects of surface finish and features to probe accuracy.

The following code will be used to identify experiments. (CDE-xx-xx) The letters "CDE" stand for Cavity Digitization Experiment, and indicate this experiment has been designed, conducted or adapted by KSC project, cavity digitization group personnel. The first "xx" simply represents the numerical order in which the experiment was codified. The second "xx" is a two digit representation of the year. The first "xx" will start with "01" for each calendar year.

CDE-01-90

Title: Repeatability of the Candid Logic Precimeter Probe.

Outline: Conduct measurements of various materials, at various angles with the probe and compare the results to values obtained by a different means. Repeat experiments to determine repeatability.

CDE-02-90

Title: Optimal range determination and scanning angles.

Outline: Measure the distance to an object of ideal material for detecting the typical depth 1" or 2" over the entire range of operation. Determine the accuracy for each range by comparing the measurements to measurements of a known accuracy.

CDE-03-90

Title: Target orientation effect upon probe accuracy.

Outline: Rotate a flat target which is perpendicular to the laser beam, or tilt the probe into certain degree. Record the target, the tilt angle and indicated distance. Then make a correlation to accuracy and laser beam incidence angle.

CDE-04-90

Title: Vibration quantification in one dimension.

Outline: Vibrate a flat target with the displacement around 0.45"-0.001" and make rapid measurements with the probe by using a computer. Analyze the data to quantify the movement along the laser beam to describe the vibration.

CDE-05-90

Title: Elementary cavity digitization.

Outline: Use an X-Y table to move the probe across a rectangular cavity. Coordinate the probe measurements with a personal computer. Output the cavity representation in the form of x-y-z points.

CDE-06-90

Title: Displacement feedback

Outline: Use a triangular block with known orientation to indicate the offset of the probe from a reference point.

CDE-07-90

Title: Effect of the corner radius of a "sharp" edge.

Outline: Determine the location of an edge using the probe in conjunction with the motion control system. Then vary the radius of the corner and evaluate the ability of the probe to still detect the edge.

Conclusion

These experiments were derived from a discussion between Tom Pax, Jimmy Hwang, and Labiche Ferreira following a meeting with Dr. Hosni.

The abstracts are only a very brief description of each experiment. More work is needed to construct the experiment. Also some experiments will require specific work intensive projects to carry them out efficiently. For example, personal computer programs to interface with the probe controller and motion controller.

As with the experiments, projects should be tracked according to the following code. (CDP-xx-xx-XX) The letters "CDP" representing Cavity Digitization Project. The remainder of the code being similar to the experiment code. The last "XX" will either be not present, one letter or two or more letters. If letters are present the project would be a sub project of the original project. Example CDP-01-90-AD: This notation indicates the following projects exist: CDP-01-90, CDP-01-90-A, CDP-01-90-AA, CDP-01-90-AB, CDP-01-90-AC, and CDP-01-90-AD. The last five are all subprojects of the first one and the last four are subprojects of the second. The last four are independent of one another.

# Appendix IV

## Sample Publications

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# TOOL PATH GENERATION FROM SURFACE MAPPING OF AN OBJECT.

Yasser Hosni, Jueng Shing Hwang, Labiche Ferreira
Department of Industrial Engineering and Management Systems
University of Central Florida
Orlando, Florida 32816.

## ABSTRACT

*This paper describes an algorithm which receives scanning data of an object in the form of an X, Y, Z representation and transforms it into a tool path. A data reduction stage manipulates the data into a manageable number of points. A geometric data extraction module identifies what these points represent. These serve as an input to the surface recognition module that identifies what kind of surface it is, i.e. planer, taper, or edge. A Numerical control (NC) program for the tool path is then generated for either the fabrication of the object or its die.*

## INTRODUCTION

With the advent of machine vision systems the lead time for producing the final product has been substantially reduced. A typical manufacturing cycle consists of three phases: design, production process planning and fabrication. In each of these phases, computers have widely been used.

Efforts in the past have been directed at automating the tasks right from the drawing board stage to the final production of the product. Such technologies include computer-aided design (CAD), computer-automated process planning (CAPP), and computer-aided manufacturing(CAM) including computer-aided NC programming. Among the three, CAD and NC programming are closely related to the manipulation of geometric shapes. Ideally a CAM system should be capable of accepting the geometric data in any form in order to generate NC code. However an academic survey of commercial NC programming systems revealed, that a total automation of the NC programming process does not exist.

Surface mapping or scanning is the process of digitizing geometrical information of an object's surface. A prime purpose for surface mapping of an object is to use the data for manufacturing the object or a die for its fabrication. Scanning may be done using a variety of methods such as laser triangulation or Moire method. The data generated after scanning is an X, Y, Z representation of the surface or object. The next stage is to use this data for generating a NC program for machining the object or its die.

This paper describes a method for generation of NC code from the X, Y, Z representation for a simple rectangular object through the use of an algorithm which extracts relevant information needed for the generation of NC code. The algorithm may be modified to handle a wider range of geometric entities.

The paper starts with a brief description of the surface mapping techniques followed by a description of the different modules for NC code generation.

## SURFACE MAPPING TECHNIQUES

The most promising surface mapping techniques are the laser scanning ( triangulation ) and Moire technique.

### Laser Triangulation

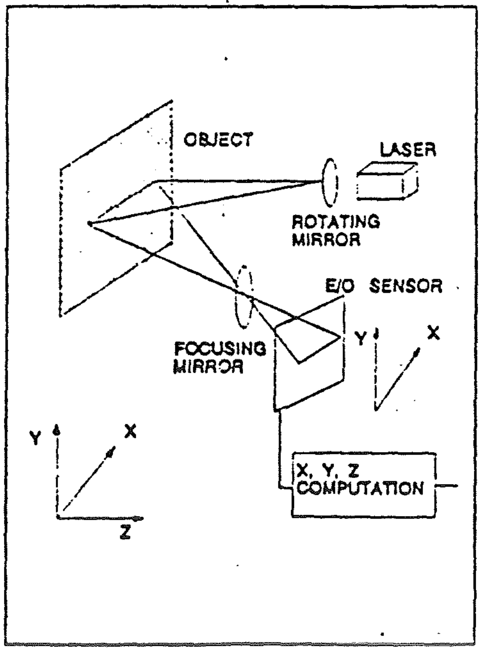


FIGURE 1 - CONFIGURATION OF LASER SCANNING DEVICE.

The basic configuration of a 3-D laser scanning device consists of a laser light source which produces a narrow light beam which is

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scanned across the object to be measured through the use of a two dimensional mirror scanner. A lens collects the reflected beam and displays it on an Electro-Optical ( E/O ) position sensor. The linear position of the reflected light, along with the angles of deflection of the scanner are used to calculate the 3-D coordinates of a point on the object's surface. Figure 1 depicts the basic configuration of a 3-D laser scanning device.

Moire Technique

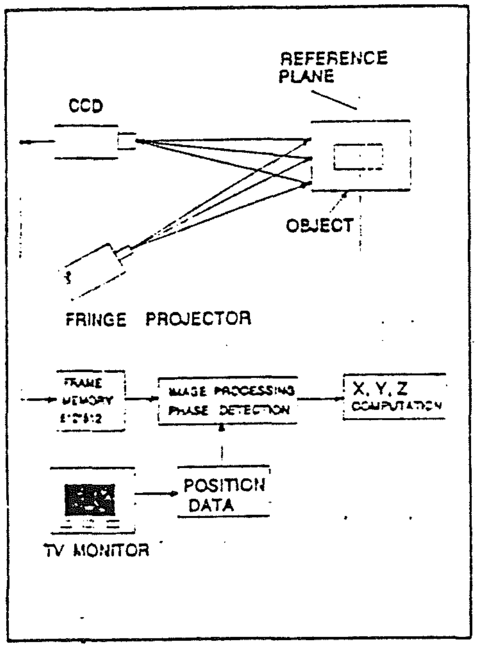


FIGURE 2 - SCHEMATIC REPRESENTATION OF THE MOIRE METHOD.

In the Moire technique, an X-Y-Z representation of an object is obtained by projecting equally spaced fringes onto the object. A 2D picture is captured by a charge couple device ( CCD ) and consequently digitized and stored as a frame in a computer. The phase shift of the light fringes on the image leads to the calculation of depth values for every point. Figure 2 is a schematic representation of the Moire technique.

## TOOL PATH GENERATION SYSTEM

The surface mapping to tool path algorithm developed is for a simple rectangular object with planer surfaces and grooves. The object in figure 3 is used for demonstration of the algorithm. The following assumptions need to be considered:

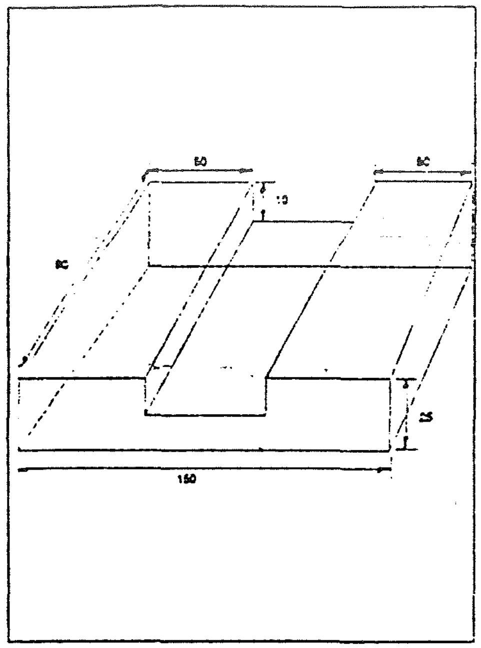

FIGURE 3 - SAMPLE PART

1) Surfaces do not have a gradient in the any direction.
2) The variation of surface depth is only in the Z direction.
3) The scanning intervals in the X and Y are predefined.
4) The number of scanning points per line is known.

The output after surface mapping an object is a X-Y-Z representation of the object. The data has to be analyzed and presented in a format which is acceptable for a CNC machine. This involves the following stages:

1) Data reduction.
2) Geometric data extraction.
3) Surface recognition.
4) NC code generation.

Both the laser triangulation and the Moire method for surface mapping result in an enormous amount of data. The data reduction stage reduces the vast amount of data generated to a manageable amount which will suffice for NC code generation. This forms the input to the geometric data extraction module. The purpose of this stage is to determine what these points represent, that is whether these points represent a line, arc, circle, or edge. The output of this stage serves as an input to the surface recognition module. This module determines the relationship between the geometric entities identified in the previous stage. In the NC code generation module the NC code is generated based on the type of the surface feature that have been identified.These stages are described in detail in the following

sections. Figure 4 depicts the overall system.

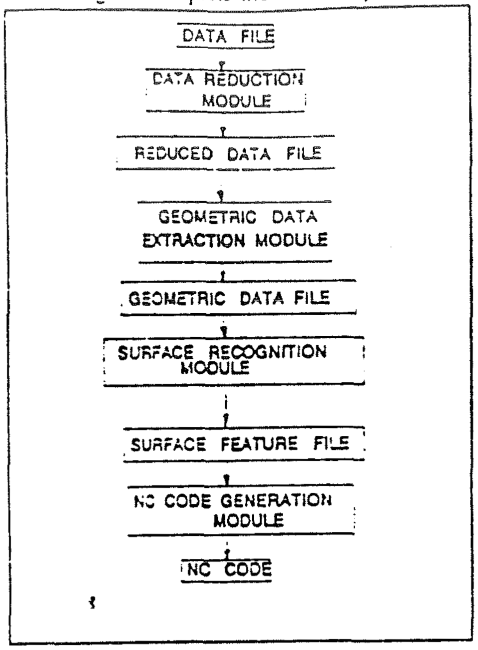


FIGURE 4 - FOUR STEP PROCEDURE FOR NC CODE GENERATION.

## DATA REDUCTION MODULE

An enormous amount of data is generated after scanning. Analysis of this data revealed that the object was scanned at intervals relatively close to each other. This generated an amount of data in excess of that needed for the tool path generation. The following options are available :

1) Digitize only at critical points. Thereby limiting the points necessary for the generation of tool path statements.
2) Reducing the data to a reasonable amount. This would mean that points in the data file would be analyzed to determine if they were a part of a line, curve, etc.

This would include analysis of the X, Y, Z points contained in the data file. A description of the proposed algorithm for data reduction and stages leading to generation of NC code are described in the following sections. Figure 5 shows the flowchart for this stage. The steps involved in the data reduction algorithm include:

1) Create a record for each scanned line,
2) Consider the first point - P[i], from the data file. This point will be used as a reference point.
3) Take the second point - P[i+1].
4) Compare X[i] with X[i+1] or Y[i] with Y[i+1].
5) If X[i] = X[i+1]
   or
   Y[i] = Y[i+1]
   Then
   compare Z[i] and Z[i+1].
6) If
   Z[i] = Z[i+1]
   retain P[i].
   If not go to the next point.
7) Consider P[i+1] ( if P[i] has been retained), and compare it with the next point. Repeat steps 5, 6, and 7.

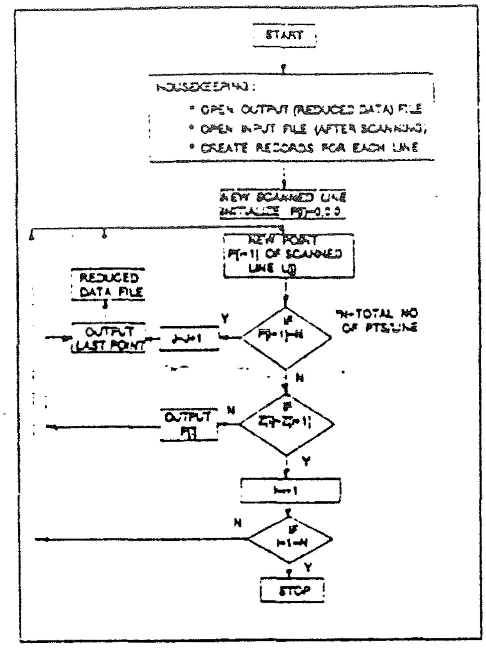


FIGURE 5 - DATA REDUCTION MODULE.

A record is created for each scanned line. The result of this data reduction stage is a reduced data file of a manageable size. This file then serves as an input for the geometric data extraction module.

## GEOMETRIC DATA EXTRACTION MODULE

The next step is to determine what type of line these points represent. For example a straight line, arc, circle, etc.. For the sake of simplicity the case of a line will be considered.

The data generated after scanning a straight line consists of a string of points. However only the starting and end points are necessary to define the segment of a line in the same elevation. The line identification procedure determines if the string of points represent a straight segment of each scanned line. Figure 6 shows the line identification

procedure.

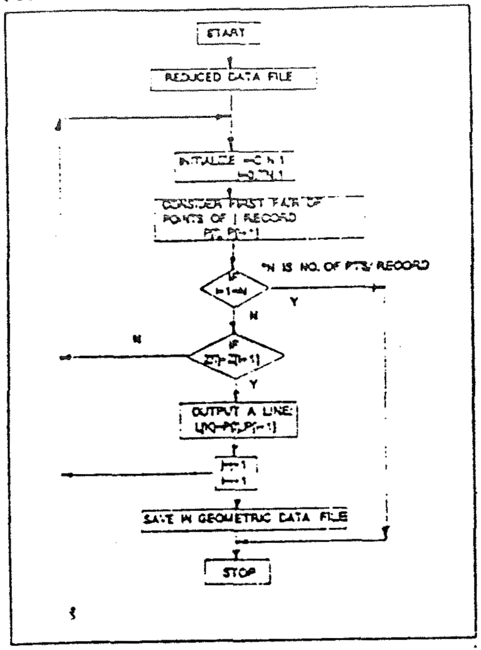


FIGURE 6 - GEOMETRIC DATA EXTRACTION MODULE.

The procedure consists of determining the start and end points of a line. The structure of the algorithm is as follows:

1) Take the first point (P[i]) in the first record.
2) Compare it with the second point (P[i+1]) of the same record.
   If
   Z[i] = Z[i+1]
   then record a line. Example -
   Line (L) =P[i], P[i+1].
3) Repeat these steps for all of the points in a record.

The output of this forms an input for the surface recognition module, which identifies the relationship between these lines.

## SURFACE RECOGNITION MODULE

Three pieces of information are important for NC part programming application:

(1) the location of each surface feature,
(2) the type of each surface feature, and
(3) the relationship between each pair of surface features.

The next step after determining which geometric shape the points represent is to determine the relationship between these shapes. These lines represent an edge or are a part of a surface which might be represented by three or more points. Figure 7 shows the flowchart for this stage.

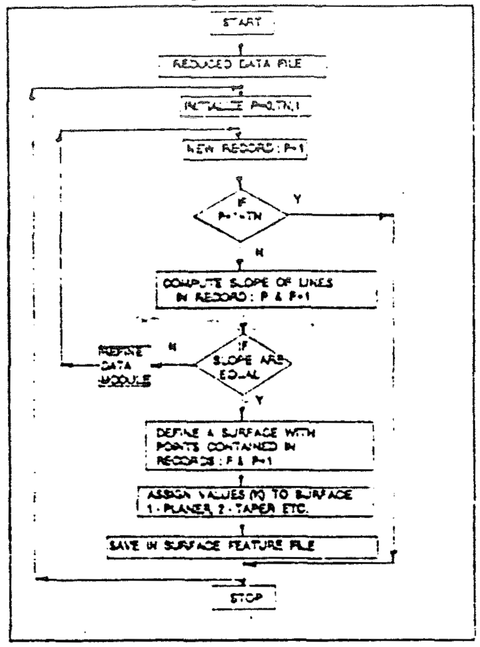


FIGURE 7 - SURFACE RECOGNITION MODULE.

The structure of the algorithm for determining the relationships between the entities is described below:

1) Consider the first set of points contained in the first record - P, (that represent the first segment of the first scanned line ). Compare it with the first set of points of second record - P+1, of the second scanned line.
2) The slopes between these points are then computed. If the slopes are equal, then this could be taken to be a planer surface. If the slopes are not equal, then a change in surface orientation is recorded, i.e. taper, convex, etc.( not yet considered ).
3) If the slopes of the two lines are equal then a surface is recorded which can be represented by these four points.
4) Steps 1 - 3 are repeated for each segment within every scanned line.
5) The relationship between surfaces should be stored in the order in which they are recognized. These will be called in the same order for NC code generation.
6) Each stored surface is given a code as an identification, i.e. 1 -for planer, 2 - for taper, etc.. This data forms an input for the NC part program generation algorithm which is described below. This data file is referred to as the surface feature file.

## NC CODE GENERATION MODULE

Surface orientation and locations of both the start and end points of each feature are available from the surface feature file.The routine of the NC code generation algorithm is described below and the flowchart of the algorithm is shown in figure 8.

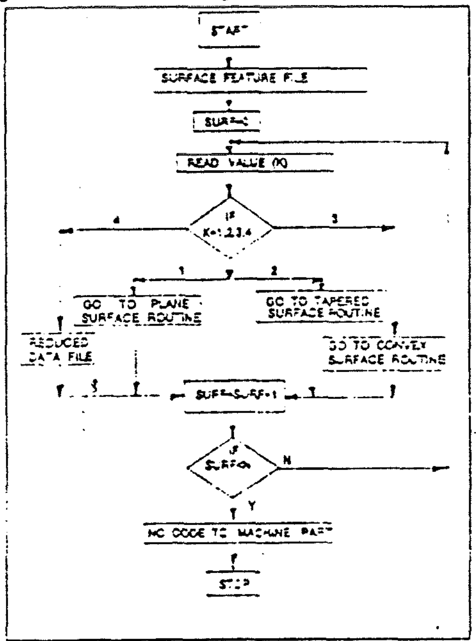


FIGURE 8 - NC CODE GENERATION MODULE.

1) Read the surface code (k) of each surface ( which was identified in the previous stage ).
2) Set depth of cut (d) and feed rate (f).
3) Based on the value of K, call the appropriate sub-routine for machining that surface. That is, the surface could be planer, circular, convex or concave. Depending on this value of K, the routine from the main program jumps to the sub-routine for generating NC code for the appropriate surface.
4) Repeat this procedure for all the surface features contained in the surface feature file.
5) After all the surface features have been processed, select an appropriate depth of cut for the finish cut.
6) Move the tool to the appropriate position and finish cut to generate the shape desired.

The output of this stage is a numerical control program that can be used to machine the part.

## CONCLUSION

Translating data points resulting from scanning into a NC program is not an easy task. Data has to go through several algorithms'routines before its geometric configuration is identified. The algorithm presented here is an attempt to automate a process traditionally handled through user interface. The human identifies surfaces, planes, etc. and critical dimensions.

The algorithm described in this paper is for planer surfaces, where a minimum of three points are needed to define a plane. These planes are then used to define boundaries and edges.The algorithm is in its initial stage. The expanded version to handle a variety of configurations is being studied. Complex cases where surfaces with varying curvatures require previous knowledge about the surface characteristics, so that the proper algorithm will control the tool motion. A major benefit of the surface mapping to tool path algorithm is its elimination of human labor in generating NC code.

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# DESIGN OF A WORKSTAND FOR OVERHEAD OPERATIONS: CASE OF THE SPACE SHUTTLE HEAT-TILE REPLACEMENT

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## SUMMARY

Operations conducted on the space shuttle at Kennedy Space Center (KSC) involve tasks such as orbiter heat tile inspection, repair, and replacement. Although tile and other thermal protection material are used on the entire orbiter exterior, work involving the lower surfaces is the most challenging to the tile technicians since a great deal of work is done "out of position" i.e., upside down.

Access to the lower surface tile is achieved from floor level by using various designs and sizes of workstands, some portable, some not. Most often, one or two technicians are involved in a given task.

Presented in this paper is a design of a seat to be installed on a workstand for overhead tasks. The design considers ergonomic factors dealing with upper body support for the technician when performing the task in less than optimal position. Other factors are practical in nature such as portability, access to full circumference of the work platform, and height adjustability to permit optimal positioning of workstand for access to all tile on the lower surfaces for the orbiter.

## INTRODUCTION

The NASA/KSC, and the University of Central Florida (UCF) are presently investigating improvements in the design of workstands used in performing tasks related to the repair and maintenance of the Thermal Protection System (TPS) on the Space Shuttle Orbiter vehicles. The overall objective of the study is to expedite repairs and to improve the accuracy with which these repairs are accomplished.

TPS maintenance is performed after each flight on all external surfaces of each of the orbiters, as well as in the payload bays. However, since most damage to the TPS is sustained on the lower and flight control surfaces, particularly in the aft section, the research team is restricting its study to maintenance tasks performed from stands positioned on the shop floor.

The configuration of the orbiter and the tasks performed on it (study limited to lower and flight control surfaces) require that virtually all processes be performed in non-standard work positions, that is, overhead.

The literature searched indicates that there is little data available on task performance in these postures. In fact, the postures and positions assumed are not recognized as anthropometrically acceptable for precision work when considering the limits of human reach and vision. It is evident that technician performance may be degraded by problems associated with visibility of the work area and fatigue brought on both by working in less than optimal postures, and in elevating the eyes and rotating the neck backward to view the work area. Further, the work positions assumed by technicians, and the mobility/adjustability of the stands have significant safety implications.

## WORK ENVIRONMENT

Processing of the TPS of the orbiters is unique in the aerospace industry due to several conditions existing in the Orbiter Processing Facility (OPF) environment, the design of the orbiters themselves, and the nature of the tasks accomplished. Following are some characteristics of the work environment which may affect workstand design.

1. The thermal tile are easily damaged by contact with equipment, tooling, workstands, or the skin of the technicians.

2. Many maintenance activities, both on the vehicle and the tile, are performed simultaneously; hence, the work area is typically crowded by personnel, equipment, and workstands of various designs. All of these obstacles must be "worked around." Figure 1. shows the working place around the orbiter, ready for maintenance operations.

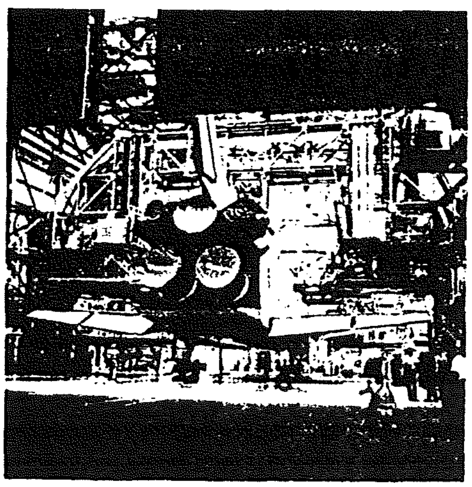

Figure 1. Work area in the OPF

3. The environment is restrictive in the materials and designs that can be used in the construction of the workstands. Primary restrictions concern the flame spread rate and out-gasing under fire conditions of the materials used in construction, as well as the mobility of the stands and the level of cleanliness that must be maintained.

4. Repair or replacement of TPS components requires extreme precision in most cases, dictating that the stands be rigid and stable, when work is performed.

5. Most tasks are presently performed in out-of-position postures, that is overhead. New stand designs should minimize fatigue complications in these postures.

6. The maintenance processes vary significantly in the surface area that is covered in accomplishing them. Repair of individual tile and removal and/or bonding of new tile is typically restricted to an area of one square foot. Measuring of the step and gap between several tile may typically have the technician traversing areas of several feet.

7. Most of the processes accomplished in TPS maintenance require the labor of only one person. However, all processes are inspected and approved by quality control and engineering personnel at numerous stages. Hence, ingress and egress from the working/inspection position must be accomplished easily and quickly.

8. Task accomplishment is heavily dominated by documentation and referral to written procedures--there must be immediate and easy access to paperwork and manuals.

## DESIGN CRITERIA

1. The workstands must provide easy access to the lower surfaces of the orbiters which range from 8 to 12 feet from the shop floor in the OPF. Male and female technicians of normal height ranges use the stands.

2. The workstands should have infinite height adjustment to accommodate the range of height of the work areas, as well as the range of height and reach of the technicians. The stands' height should be easily adjustable by one person, and preferably would be adjustable from the technician's working position.

3. The design should provide postural support for the technicians in accomplishing overhead processes thereby minimizing the effects of fatigue and visibility of the work area.

4. It is recommended that the use of electrical and/or hydraulic power use be minimized for safety reasons, i.e. cables, hoses, etc., should not be extended around the orbiter on the floor of the work place. Manually powered devices is a recommended substitute.

5. If wheels are to be used on the workstands it should be of large enough diameter to allow easy passage over floor gratings used to cover equipment chases and drainage channels.

6. Proof testing - stands should be able to withstand static loadings of 375 lbs. for each person that they will accommodate without failure or significant deformation. Handrails should be able to withstand loadings of 375 lbs. applied downward at a 45 degree angle from vertical Steps and/or ladder rungs should be able to withstand static loading of 375 lbs.

7. The design of the workstand must conform to NASA standards for Space Shuttle Ground Support Equipment General Design Requirements.

8. Materials used in construction must conform to NASA standards for materials permissible for use in the OPF.

9. Human engineering criteria should conform to the military standards for Military Systems, Equipment and Facilities.

## WORKSTAND DESIGN

The design strategy for the modified or new workstand is directed at increasing technician safety, decreasing the time to perform TPS processing tasks, and increasing the precision with which these tasks are accomplished.

All current and any added alternatives have, or should have, four elements included in their design:

1. The use of larger and wider wheels - minimum of 8" diameter and 2.5" width, to permit easy rolling over obstacles and zero penetration of the floor gratings.

2. Improvements in the range and ease of height adjustments.

3. Improved access to equipment and paperwork.

4. Features to allow the technician to work in a semi-reclined seating position, or as an alternative, provision for upper body support when standing while leaning backward.

The first three elements are essential. The fourth, reclining the technician, may not prove beneficial for tasks performed that traverse large areas, but should be considered essential for tasks limited to small areas such as repair of one or a few tiles, or cavity preparation and/or tile bonding to the surface of the orbiter.

Due to the space limitation in this paper, we are reporting on the design of "seat to be added to an existing workstand which is currently being used at KSC. Figure 2.a is the current workstand and the suggested location for the seat assembly. The design makes use of the unused "volume" under the stand platform in housing the seat assembly. In situations where there is a need for an operation requiring positioning of operator for long periods of time performing an overhead operation, the platform would be opened and the seat assembly would be raised to the platform level when it is to secured. Figure 2.b. shows the elements of the seat assembly, when a height adjustable mechanism (powered manually or mechanically), can raise a seated worker to the proper position underneath the orbiter. The seat is equipped with a rotating subassembly table to allow coverage of an area and it is in the proper position. The operator can then lock the table in a certain position.

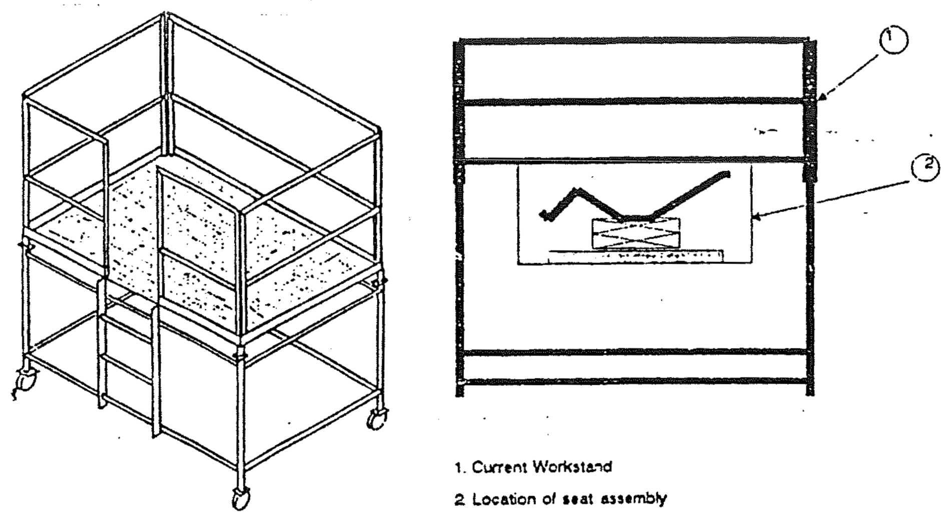


Figure 2.a.
Current Workstand and suggested location for the seat assembly.

Overhead Operations

Seat Assembly Components

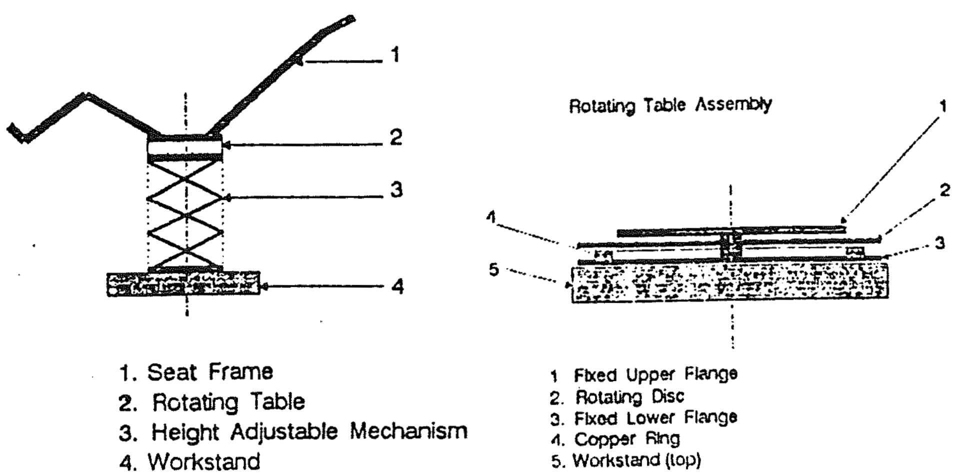


Figure 2.b.
Elements of the seat subassembly

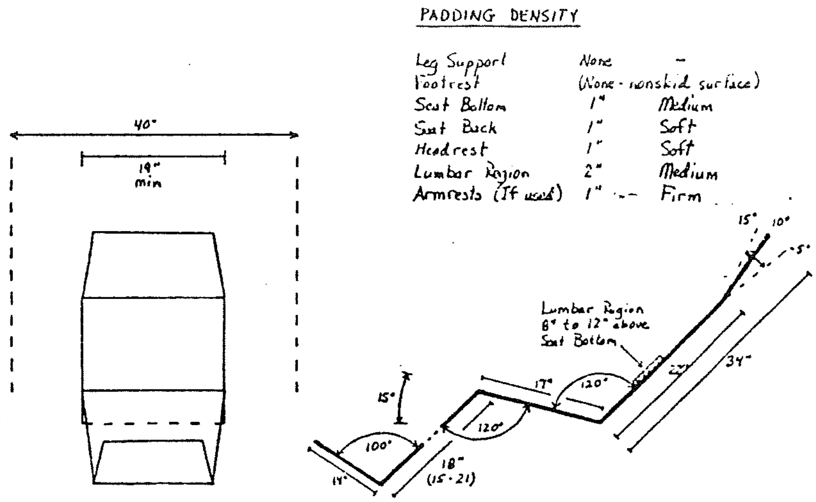


Figure 2.c.
Seat Dimensions.

Figure 2.c. is detailed drawing of the seat dimensions. It is a compromise of several criteria, but generally follow the guidelines for the average adult (lengths, angles) so as to accommodate the range of sizes for the technician population (Human scale, IE Handbook, MIL-STD-1472). Modifications may be made, but the following criteria should be adhered to:

1. With backrest angles in this range (120 degrees shown), a headrest must be used, and headrest height should not be less than 31".

2. Footrest angles should not allow knee flection of less than 100 degrees (110-120 optimum).

3. Seat bottom inclination should not be less than 15 degrees (shown) to prevent sliding downward. Angles greater than 15 degrees, if used, will make ingress or egress more difficult.

4. Footrest angle should not be less than 90 degrees (100 degrees shown).

5. Lumbar support should be maintained, via thicker padding or contouring of the backrest.

6. Knee to ankle distance should be adjustable over the range of 15" to 21".

7. Optimum headrest angle for reclined seating positions when viewing objects near the horizontal place is 10 degrees (shown). However, for this application where the technician is looking overhead, the headrest angle should be adjustable.

8. Seat width should not be less than 19" and hip clearance not less than 22".

9. Work area width should be unobstructed for a width of 40" to allow full arm movement.

## CONCLUSION

The ergonomic design of a workstand should be based not only on anthropometric data but also specific requirements of the work itself and workers behavioral pattern. The space shuttle heat tile replacement represent an unique working environment with specific requirements.

This paper presented a workstand design based on the specific design criteria established for the TPS repair and maintenance tasks. As demonstrated in this paper, the general ergonomic guidelines for workstand design should be modified under practical conditions in order to improve its effectiveness. The present design can be adapted for other aerospace industries which have common problem with overhead operation.

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# DESIGN AND EVALUATION OF A WORKSEAT FOR OVERHEAD TASKS

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Workers in some industries such as the aerospace industry are frequently required to work in awkward overhead positions resulting in physiological and biomechanical stress to the workers as well as degraded worker performance. General ergonomic guidelines can be used to provide the workers with more comfortable work positions which will improve the productivity and safety of the workers. This paper presents the design and evaluation of an ergonomically designed workseat which considers ergonomic factors dealing with whole body support for the workers when performing tasks in a less than optimal position. The workseat allows the workers to perform their tasks in semi-reclined positions instead of the normal standing overhead position. A prototype of this workseat was produced and evaluated both objectively and subjectively.

## INTRODUCTION

The Thermal Protection System Repair and Maintenance Procedures for the Space Shuttle Orbiters performed on the lower surface dictates less than optimal working positions for tile technicians. The technicians are forced to work in uncomfortable, fatiguing overhead positions with no back or neck support. An ergonomically designed workseat providing more body support and comfortable working positions was designed and evaluated. The evaluation of the workseat was conducted by simulating some overhead operations performed by tile technicians at NASA (KSC). Five tile technicians from NASA (KSC) participated as human sujects during the evaluation process. Their task performance and general and body part discomfort with and without the support of the workseat were measured and compared.

## METHOD

### Design of Workseat

From the existing ergonomics database and literatures, the following design criteria for the workseat was established (Diffrient et al., 1981, Grandjean, 1990, MIL-STD-1472C).

1. With backrests angles in approiaximately 120 degrees, a headrest must be used, and headrest height of at least 31".
2. Footrest angles should not allow knee flexion of less than 100 degrees (110-120 optimum).
3. Seat bottom inclination should not be less than 15 degrees to prevent sliding and ensure ease of egress and ingress.
4. Footrest angle should be at least 90 degrees.
5. Back support should be maintained, via thicker padding or contouring of the backrest.
6. Knee to ankle distance should be adjustable over the range of 15" to 21".
7. Adjustable headrest angle with 10 degrees where the workers are looking overhead.
8. Seat width should be no less than 19" and hip clearance of at least 22".
9. Unobstructed work area width of 40" to allow full arm movement.

Figure 1 is a detailed drawing of the seat dimensions. It is a compromise of several criteria, but generally follow the guidelines for the average adult (lengths, angles) so as to accommodate the range of sizes for the worker population. A prototype of the workseat was fabricated and evaluated.

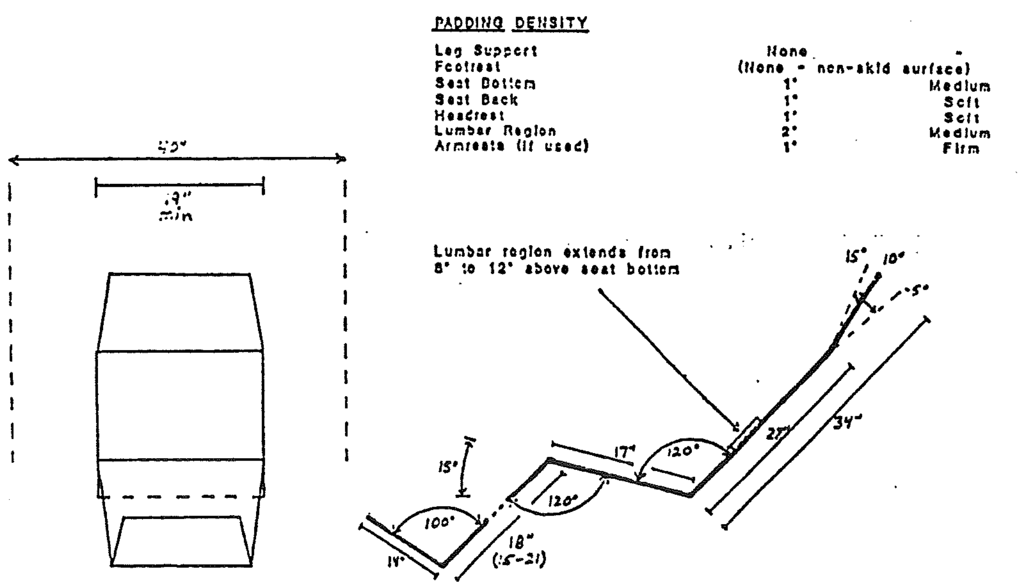


Figure 1 Workseat Design

## Experimental Evaluation

An experiment was conducted through the simulation of actual Thermal Protection Repair and Maintenance Procedures performed at the NASA (KSC) Orbiter Processing Facility in addition to general application tasks. Thus, the evaluation results will be a direct reflection of the possible improvement of worker performance and comfort of NASA workers and other applicable industries.

Processes P-601, Installation of Pillow (Alumina) Gap Fillers, and P-301, Tile Installation were chosen for simulation. The two processes were chosen because of the high frequency of their occurrence and ease of simulation. In addition, Rotary Pursuit Tracking and Weighted Overhead Work tasks were also included to simulate general overhead task applications.

The entire processes of gap filler and tile installation were not to be completed during this experiment. Several of the prepatory and prefit tasks are unnecessary, irrelevant, and far too time-consuming for the experimental purposes. The work performances of the subjects was monitored throughout the processes. The type and the time duration for each task were observed and recorded using work sampling methods at thirty second intervals.

Rotary Pursuit Tracking is designed to allow for human performance measurements in the area of accuracy by simulating fine motor skills and is a commonly accepted and recognized method of measurement in the ergonomics field. The tracking device consists of a fluorescent light source rotating in a circular motion and a stylus wand with a photocell at the tip. The subjects pursued the moving light target with the stylus, attempting to keep the stylus and light moving together on the circular path. The photocell initiated the digital stop clock which measures the cumulative time of successful pursuit. By keeping the duration of the task, sensitivity of the sensor, and speed of rotation constant for all subjects, an effective measurement of accuracy was easily obtained. The pursuit tracking task was limited to two five minute sessions with a rest period of five minutes between each session, the sensitivity set at level 10, and the speed was set at 40 revolutions per minute. The amount of time the subject could successfully pursue the light source was recorded as time-on-target and was recorded at one minute intervals during both sessions of 5 minute duration.

The Weighted Overhead Task was also included as a general application experiment, in order to measure the endurance time The task readily served as simulation of overhead work involved heavy objects. The subjects were instructed to align a weighted box (approximately 15 pounds) in the cavity positioned overhead. The subject were further instructed to hold the weighted box overhead in that position as long as they possibly could without moving the box from the cavity. Contact sensors mounted inside the cavity were to signal by the light, connected in series with the contacts, when full contact was first achieved between the box and the sensors within the cavity and when that contact first faltered. This task served to measure overhead endurance time. By monitoring the time needed for alignment and the maximum time a subject could support the weighted box, an accurate measure of endurance was obtained.

Performance Parameters

The performance parameters measured were task completion time, task accuracy, endurance time, and body discomfort. The general and body part discomfort of each tile technician was subjectively evaluated upon the completion of each process.

During the experiment the performance and discomfort of the subjects during actual process activity were measured in an effort to contrast the level of performance and discomfort associated with both the typical standing overhead working position and the semi-reclined and supported position offered by the ergonomic seat.

Five volunteer tile technicians from KSC participated as human subjects. They were fully instructed as to the nature and purpose of the experiment and encouraged to perform the processes at their usual level of effort and rate.

The experiment involved five subjects and four processes; two tile repair and maintenance, P-601 and P-301, simulations and two general application tasks, Rotary Pursuit Tracking and Weighted Overhead Tasks. The whole experiment was replicated once in order to reduce the experiment error.The subjects performed the four processes in two working positions; standing and seated. The experiment required four separate visits from each subject for a time duration of approximately 1.5-2 hours each. Each visit was virtually the same except for the position in which the processes were completed. Each subject completed all four processes on each visit. During the performance of each process, the worker performance and discomfort of each subject were measured and monitored. The parameters measured were task completion time, endurance time, task accuracy, and body discomfort.

RESULTS

The Statistical Analysis System (SAS 1984) was used to analyze the data obtained during the experiments. The independent variable used was working position, i.e. standing, seated. The dependent variables were task completion time, endurance time, task accuracy, and body discomfort.

Figure 2 shows the task completion time during the tile processing. As the figure reveals, there was only an insignificant difference in the task completion time. The endurance time measured during the weighted overhead work task is depicted in Figure 3. The figure illustrates a statistically significant increase of 62.7% in endurance time. The Rotary Pursuit Task was used to measure accuracy. Figure 4 shows the accuracy percentage levels associated with both postures for both sessions of tracking. There was a significant increase of 4.2% in the amount of time-on-target from the standing to the seated position during the first session and 3.44% increase in the amount of time-on-target from the standing to the seated position in the second session. Utilizing the scaled discomfort index of range of 0 to 10, Figure 5 illustrates the average level of discomfort associated with each body part throughout the stages of the experiment. Figure 6 shows the varying levels of discomfort associated with each position by task. As illustrated by the figures, the seated position was much more comfortable than the standard standing position.

The free response comments expressed by the subject divulged a list of shared concerns. In summary, the subjects maintained the need for work and storage space in the form of trays or tables and a waste container. They also voiced concern over dripping RTV and other chemicals and falling debris. Many of technicians stated their worry of dropping tools and materials from the workseat as well as falling from the seat themselves. Arm rests, permanently tethered tools or safety net, and a chemical and debris shield could be implemented to improve the seat design.

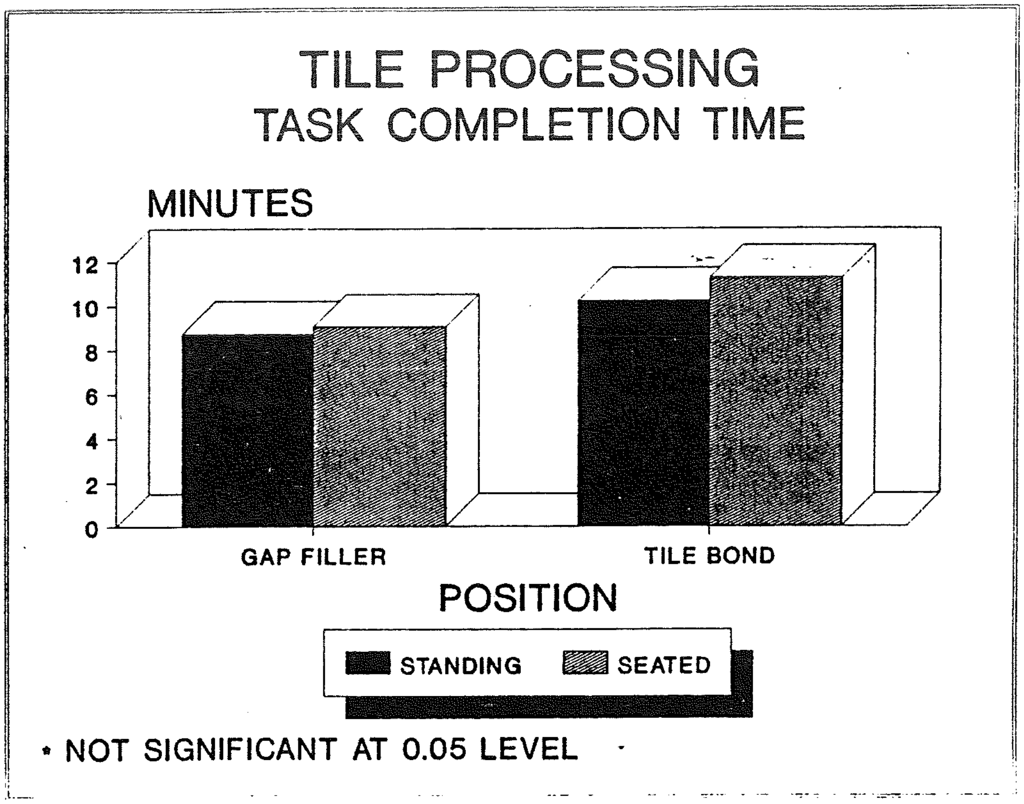


Figure 2 Task Completion Time

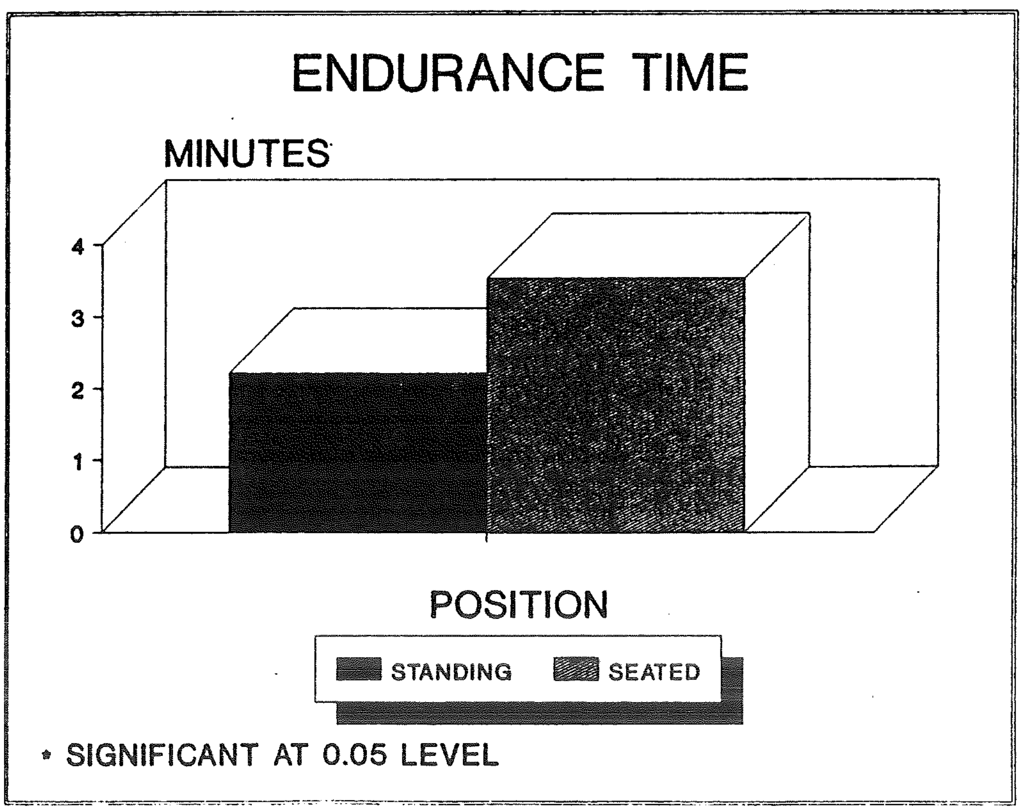


Figure 3 Endurance Time

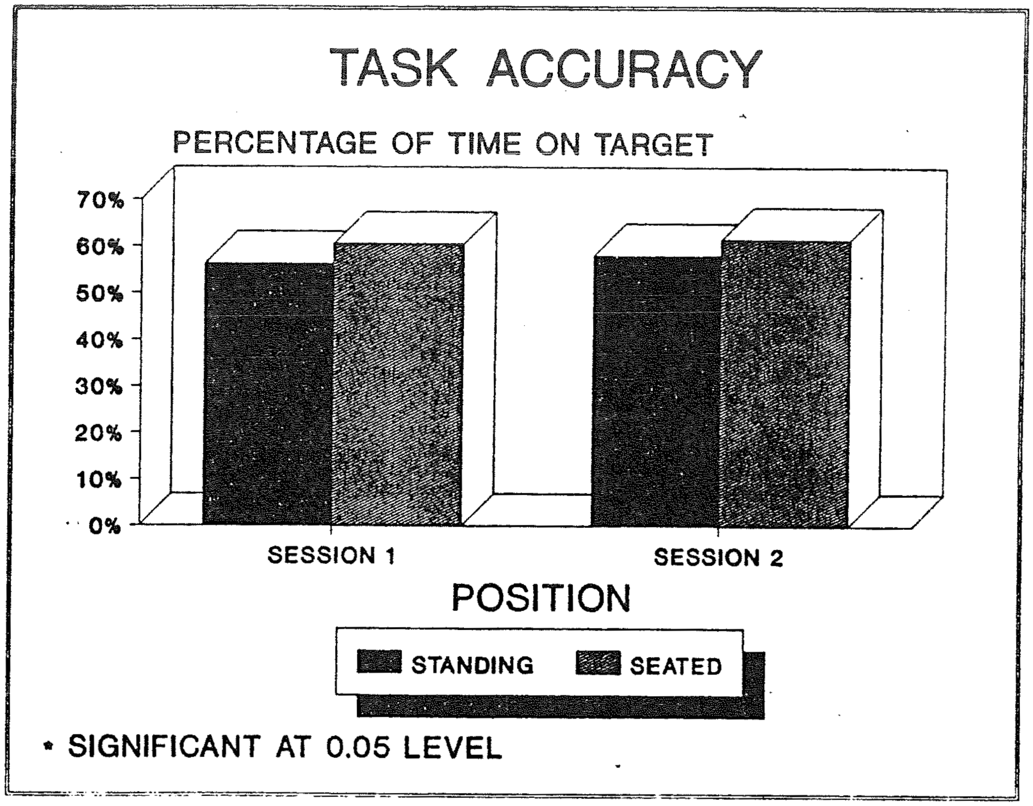


Figure 4 Task Accuracy

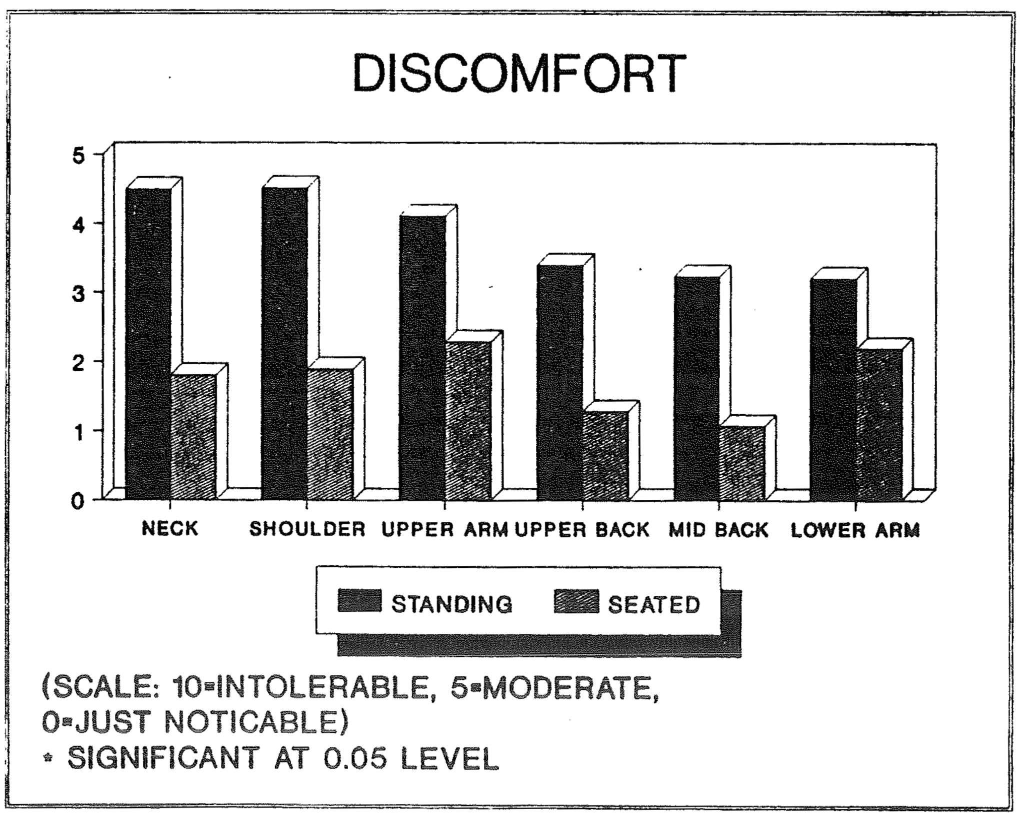


Figure 5A Body Part Discomfort

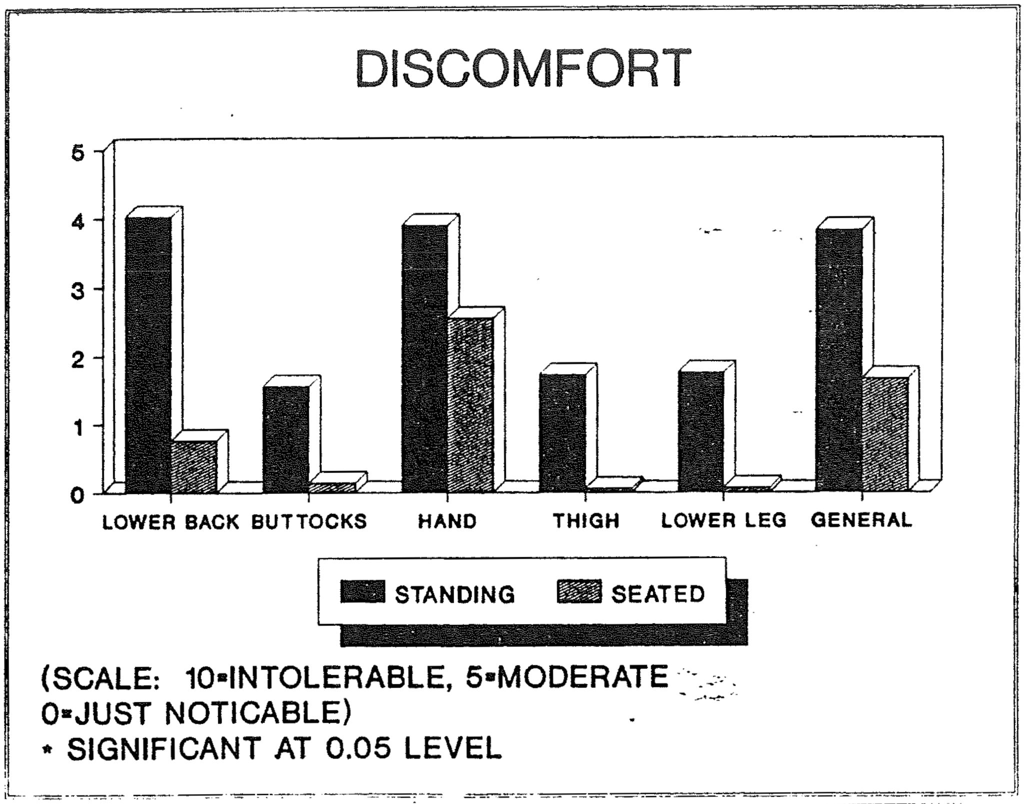


Figure 5B Body Part Discomfort

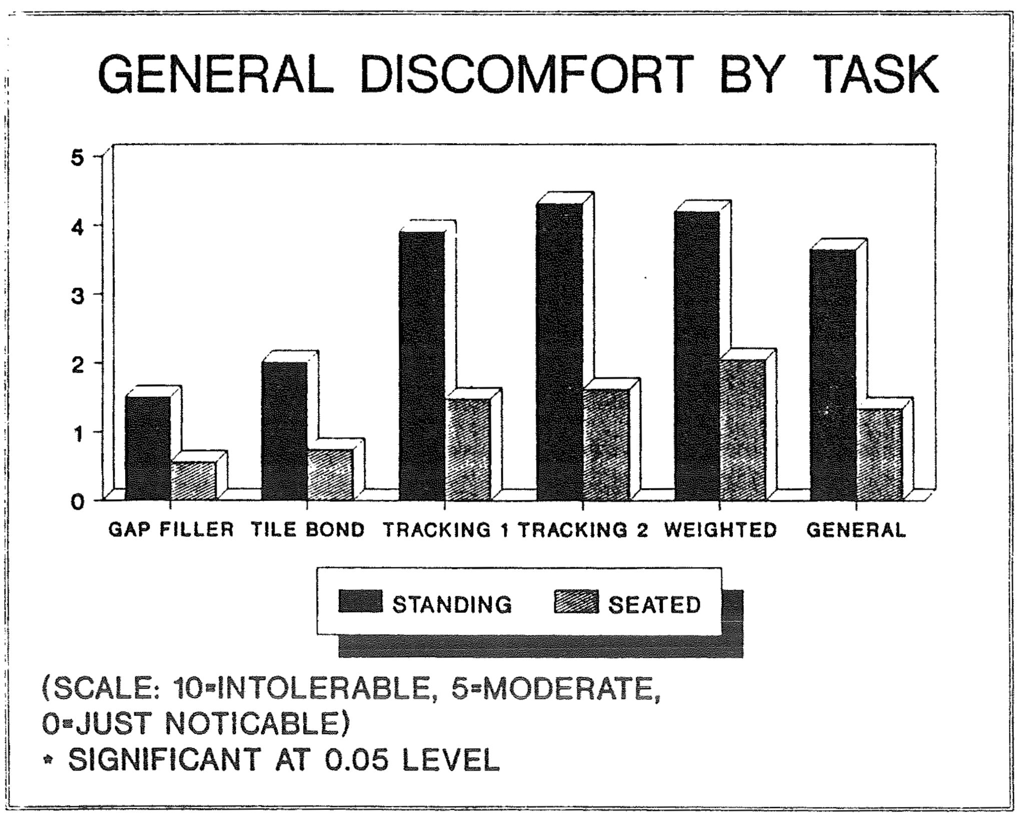


Figure 6 General Discomfort by Task

## CONCLUSIONS

The seated position was significantly superior to the standard standing working position in terms of performance and body discomfort. Initially, the results of the tile processing time were not very different. However, when coupled with the large differences in endurance time and the difference in accuracy levels which were measured over a very short period of time, it is obvious that the differences would be largely magnified over the course of an entire work shift. Furthermore, the much higher level of discomfort associated with the standard working position alone points to the seated position as a better alternative.

The results of the evaluation showed that an ergonomically designed workseat improves the quality of work, reduce task completion time and necessary rest periods, and increase comfort during overhead operations.

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